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FLIGHT VIBRATION SURVEY OF F-101A AIRCRAFT

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AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This technical note was prepared in the Environmental Criteria Section, Environmental Branch, Engineering Test Division, Flight and Engineering Test Group, under Project 1309, Task 13004. The Project Engineer on this survey was Charles E. Thomas of the Environmental Criteria Section. The survey covered by this technical note is one of a series of programs conducted on operational aircraft by the Environmental Criteria Section. The flight tests were conducted at Wright-Patterson Air Force Base by pilots of the Fighter Branch, Flight Test Division, Flight and Engineering Test Group, during the period of 1 August 1957 to 10 October 1957.

The information garnered from this effort was submitted as raw data to the requesting agency upon completion of the tests, and is now being presented in a formal report for the purpose of wider distribution.

ABSTRACT

The F-101A aircraft was surveyed to determine the vibration environment existing throughout the vehicle under all flight conditions expected in service. Approximately 32,630 data points were obtained from 25 separate locations on the vehicle during 31 test flights. The data obtained in this survey were evaluated to determine the vibration test requirements which should be specified for items of equipment to be used on the F-101A aircraft. The data indicated that, in general, the vibration testing requirements listed in Specification MIL-E-5272 are more than adequate for F-101A equipment.

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SECTION I

INTRODUCTION

The lack of sufficient data to define the actual dynamic environment in which the equipment within the vehicle operates is one of the major problems in airborne equipment design, application, testing and use. In most cases this lack of data has resulted in either (1) overdesigning the equipment, with its attendant excessive development costs, time, specimen size, and weight, or (2) underdesigning the equipment, with a resulting lack of reliability and limited service life.

To provide the necessary information, the Environmental Criteria Section, Environmental Branch, Engineering Test Division, Flight and Engineering Test Group, has implemented a comprehensive data acquisition program aimed at obtaining vibration data on all available aircraft and missiles.

This is one of a series of reports which present vibration data measured on the structure of aircraft and missiles. The primary objective of these reports is the dissemination of important dynamics data to those concerned with developing airborne accessories. These data can be used as the basis for preparing design and testing specifications, for estimating environments on flight vehicles in the "drawing board" stage, in establishing optimum location and installation practices, etc. The data in this report is interpreted only with respect to the specific vehicle under study, i. e., F-101A aircraft; no attempt is made to assimilate this information with existing data on other similar vehicles or to present complete explanations of all the vibration phenomena involved. It is intended that later reports will be published to interpret the data and to draw comprehensive conclusions concerning vibration generation, propagation, structural response characteristics, and the like. However, the test instrumentation, procedures, and data reduction methods are covered in considerable detail.

SECTION II

DESCRIPTION OF THE F-101A AIRCRAFT

The F-101A is a single-place supersonic fighter built by McDonnell Aircraft Corporation. Designed for use as a fighter-bomber, it can be used also as a long range escort-fighter. The airplane is powered by twin axial-flow J-57 P-13 turbojet engines with afterburners. Each engine is rated at a sea-level static thrust of approximately 10,200 lbs. at military power and at a maximum thrust of approximately 15,000 lbs. with afterburning at maximum power. The airplane is equipped with four 20-mm automatic guns. The guns are installed just aft of the

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cockpit in the lower surface of the fuselage and outboard of the nose gear well, two on each side. External stores can be carried on removable pylons mounted on the underside of the fuselage. Provisions have been made for carrying two 450-gallon external fuel tanks which increase the total fuel capacity to 2,979 gallons. The airplane gross weight without external load is 40,804 lbs. and, with full external tanks, it is 47,049 lbs. The following physical dimensions apply to the F-101A, S.N. 53-2440:

TABLE I

F-101A GENERAL SPECIFICATION DATA

Span	39 feet 8 inches
Length	67 feet 5 inches
Height (to top of fin)	18 feet

SECTION III

TEST INSTRUMENTATION

The test instrumentation comprised the following: (1) 60 MB Type 124 velocity pickups, (2) one Davies Laboratories Model 501 14-channel magnetic tape recorder, and (3) one remotely controlled pickup selector switch. Generally, the pickups were mounted in groups of three and oriented to sense vibration along each of the three major axes of the aircraft. These pickups were attached to the aircraft structure and the engine at 25 points of interest. The locations are shown in Figure 1 of Appendix A. A more detailed description of the instrumentation is contained in Appendix A.

SECTION IV

TEST PROCEDURE

A total of 31 test flights was conducted during this survey. Vibration records were taken during all of the normal service conditions, such as: taxi, ground runup, takeoff, straight and level flight (at selected altitudes, airspeeds, and power settings), turns, descent, landing, landing roll, formation flight, and with gunfire. Further information concerning the test procedure is contained in Appendix A.

The reels of recorded data were edited in the laboratory and each sample (approximately 5 seconds in length) was spliced into an endless loop. These loops were then placed on a Davies Model 502 tape playback system and a narrow bandwidth (10 cycles/sec) analysis was conducted simultaneously on six of the twelve channels of data by using a Davies Model 510 heterodyne type analyzer. The analyzed data were recorded on six modified Brown strip chart recorders in the form of a continuous spectrum of frequency (cps) versus transducer voltage (rms). The data points of interest were then extracted from the strip chart recordings, tabulated, and punched into IBM cards. Corresponding decks of "master cards" which contain detailed descriptive information concerning pickup locations, flight conditions, and source and order of vibration were also prepared. The extracted data and the appropriate "master cards" were then processed by means of an ERA 1103A computer. Both the vibratory double amplitude expressed in inches and acceleration expressed in g units appear in the completed data card. The data were then sorted into the desired order and graphed by an automatic plotter having IBM card input capabilities.

SECTION V

PRESENTATION OF DATA

The plots contained in this report are: (1) summary plots for each individual pickup for all of the flight test conditions, (2) summary plots for each cluster (2 to 3) of pickups at any given test point, and (3) structural "zone" plots for all of the flight test conditions. It has been found that these types of data presentation are satisfactory for use in establishing specification requirements and in estimating vibration environments in other similar vehicles. However, in instances where a more detailed analysis of the vibration characteristics is required, it is possible to present graphs showing variations of many parameters affecting vibration conditions in the vehicles. For example, graphs can be made showing variation of vibration as a function of the following parameters: (1) indicated airspeed, (2) altitude, (3) engine rpm, (4) flight condition, (5) engine order, etc. Additional plots of this type can be provided if required. A more detailed description of data handling procedures, data analysis, and presentation methods is contained in Appendix A of this report.

SECTION VI

RESULTS

In general, the data are of the discrete frequency type, as evidenced by the clusters of data points shown on the graphs contained in Appendix A. For the most part, these frequencies can be attributed to: (1) the fundamental and harmonics of the high- and low-speed rotors of the engine, (2) localized structural resonant response to the broad band acoustic input produced by the jet exhaust and aerodynamic turbulence, and (3) the fundamental and harmonics of the gunfire frequency.

As expected, the dominant source of vibration for any given structural "zone" is dependent on its location in the vehicle. In the case of the aft quarter of the fuselage, for example, one would expect the dominant source of vibration during ground runup climb and low-speed flight to be the turbulence produced by the jet exhaust; and this is the case.

A total of 32,630 data points was obtained during the 31 test flights which were conducted during the survey. The results indicated that the following vibration envelope would be satisfactory for most items of equipment used on the F-101 aircraft:

5 to 8 cps	0.150 inches double amplitude
8 to 22 cps	± 0.50 g vibratory acceleration
22 to 70 cps	0.020 inches double amplitude
70 to 500 cps	± 5.0 g vibratory acceleration

In the case of the aft section of the fuselage, the vertical and horizontal control surfaces, and the wing tip, the envelope would have to be changed as follows to account for the more severe low frequency:

5 to 8 cps	0.300 inches double amplitude
8 to 44 cps	± 1.00 g vibratory acceleration
44 to 97 cps	0.010 inches double amplitude
97 to 500 cps	± 5.00 g vibratory acceleration

Although the levels of vibration indicated on the graphs are average values, peak values having three times the magnitude of the average values have not been at all uncommon. Therefore, in the case of critical equipment, it would be desirable to conduct a frequency scanning type test to detect malfunctions. The vibratory levels used in a test of this type should be at least twice the magnitude of those specified in the test envelopes contained in this report.

SECTION VII

CONCLUSIONS

The vibration test envelope specified in Procedure XII of Specification MIL-E-5272C is not satisfactory for items of equipment which will be used only on the F-101 aircraft. The low-frequency vibration required by MIL-E-5272C is of insufficient magnitude, whereas the high frequency required by the specification is too severe compared to the actual environment.

The resonant frequency of any isolators which are scheduled for use on the F-101 aircraft should be in the range of 15 to 25 cps if satisfactory performance and service life are to be obtained.

APPENDIX A

1. Instrumentation

MB Manufacturing Company Type 124 velocity pickups were mounted in clusters (generally three) at 25 separate test points on the aircraft engine and structure. The locations are summarized in Table II and shown in Figure 1. The Type 124 velocity pickup has the following characteristics:

Nominal sensitivity	96.4 mv(rms)/in/sec(rms)
Usable frequency range	5 to 2000 cps
Temperature range	-50 to + 250° F

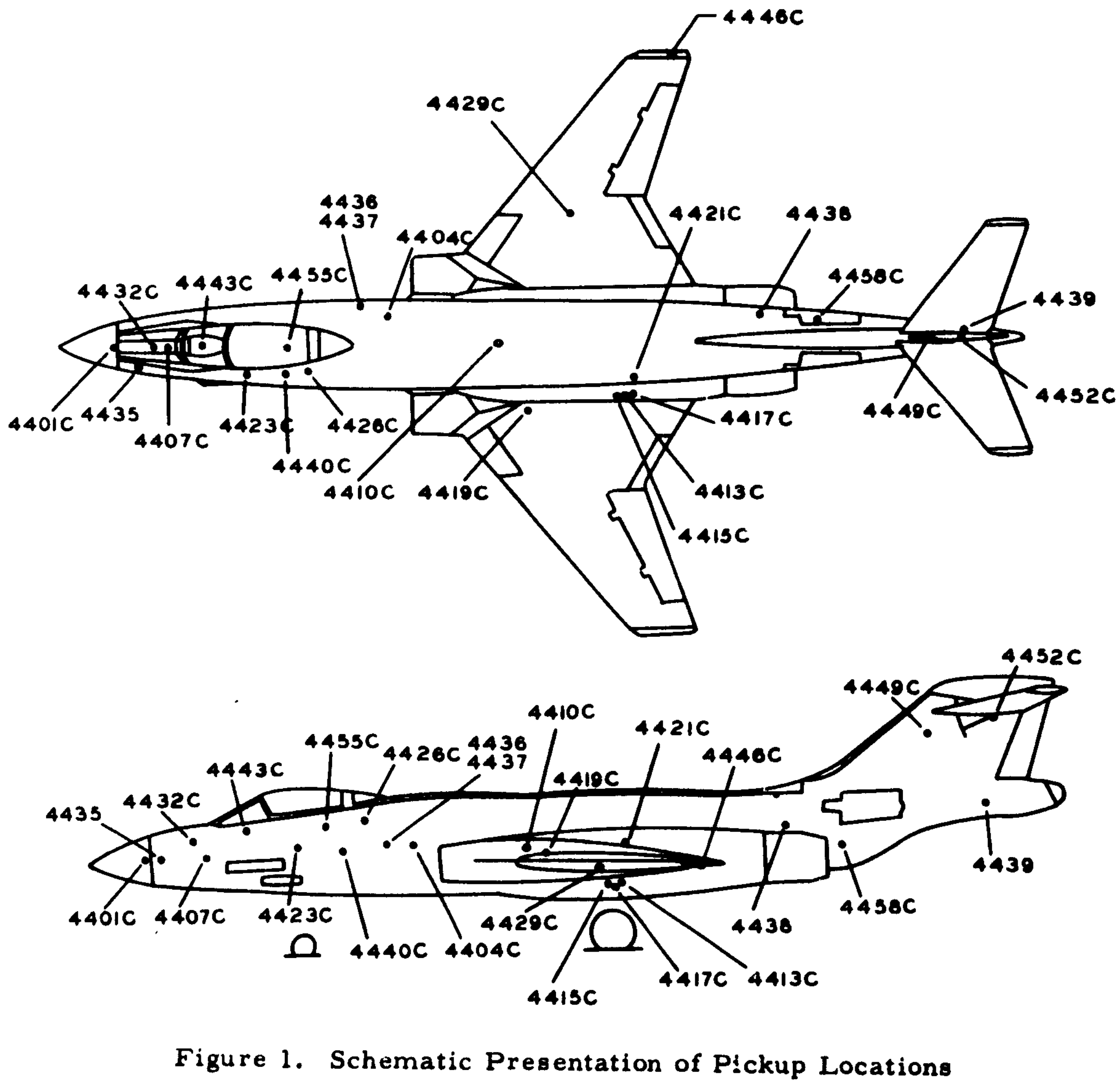

Figure 1. Schematic Presentation of Pickup Locations

TABLE II

PICKUP LOCATIONS

PUID	Location	Direction	PUID	Location	Direction
01	Structure at Base of Radar Antenna	F/A	32	Structure above Battery	Vert
02	Sta. 143	Lat	33	Sta. 196	Lat
03		Vert	34		F/A
04	Structure of Hydraulic Panel on	F/A	35	Left Side of Nose Structure Sta. 146	Lat
05	Rt. Side of Fuselage Sta. 378	Lat			
06		Vert	36	Right Side of A/C Fuselage Sta. 342	Lat
07	Shock Mounted Equipment Rack	F/A	37	Right Side of A/C Fuselage Sta. 524	Lat
08	in Nose Section Sta. 185	Lat			
09		Vert	38	Right Side of A/C Fuselage Aft Section Sta. 680	Lat
10	Structure of Engine Nacelle (Center)	Lat			
11	Sta. 484	F/A	39	Right Side of A/C Fuselage Aft Section Sta. 814	Lat
12		Vert			
13	Brush Band Section of 30 KVA	Vert	40	Electronic Equipment Compartment	Vert
14	G. E. Alternator Sta. 568	Lat	41	Sta. 296	Lat
			42		F/A
15	Sunstrand Constant Speed Drive	Vert			
16	for 30 KVA Alternator Sta. 568	Lat	43	Instrument Panel Sta. 230	F/A
			44		Lat
17	Fwd. End of Accessory Section	Lat	45		Vert
18	of J-57-P13 Engine Sta. 568	Vert			
			46	Rt. Wing Tip Sta. 600	F/A
19	Fwd. End of Compressor Section	Lat	47		Lat
20	of J-57-P13 Engine	Vert	48		Vert
21	Vert. Nozzle Section of J-57-P13	Vert	49	Structure of Vertical Fin	Vert
22	Engine Sta. 568	Lat	50	Sta. 783	Lat
			51		F/A
23	Structure of Fwd. Electronic	F/A			
24	Compartment Sta. 235	Lat	52	Stabilator Actuator Plate	Vert
25		Vert	53	Sta. 814	Lat
			54		F/A
26	Structure of Radio Compartment	Lat			
27	Sta. 290	F/A	55	Pilot's Seat Rail	Vert
28		Vert	56	Sta. 286	Lat
			57		F/A
29	Structure of Rt. Wheel Well	Vert			
30	Sta. 546	Lat	58	Aft Section Structure Rt. Side	Vert
31		F/A	59	Sta. 692	Lat
			60		F/A

A typical response curve is shown in Figure 2. The three-position mounting blocks used to attach the pickups to the vehicle structure have no resonances below 500 cps.

A Davies Model 501 14-channel magnetic tape recorder was used to record the outputs of the vibration pickups. The recorder, complete with control box and shock mount; and the pickup selector switch were installed in the nose section of the aircraft. The 26- to 28-volt DC power required for operation of the recorder and the selector switch was obtained from the aircraft DC system. The recorder was preset for a recording time of five seconds. The Model 501 recorder was an FM type having the following characteristics: (1) FM carrier frequency of 10 KC, (2) intelligence frequency response of 3 to 2000 cps, (3) dynamic recording range of 45 db, (4) tape speed of 15 inches per second, (5) total recording time of approximately 8 minutes, (6) weight of 55 lbs., and (7) overall dimensions, including shock mount, are 10-1/2 x 11 x 21 inches. The twelve data-channels had an input impedance in excess of 100,000 ohms. The thirteenth channel had an input attenuation of approximately 45 to 1 and was designed for direct connection to the engine tachometer generator. The fourteenth channel was used to record the output from an internal 10 KC (crystal-controlled) oscillator. This channel was used during tape playback to control the playback speed by means of a servo, and it was also utilized in the electronic compensation of the tape playback and analysis system. The recorder used 1-3/4-inch wide magnetic tape in 400- to 600-foot reels.

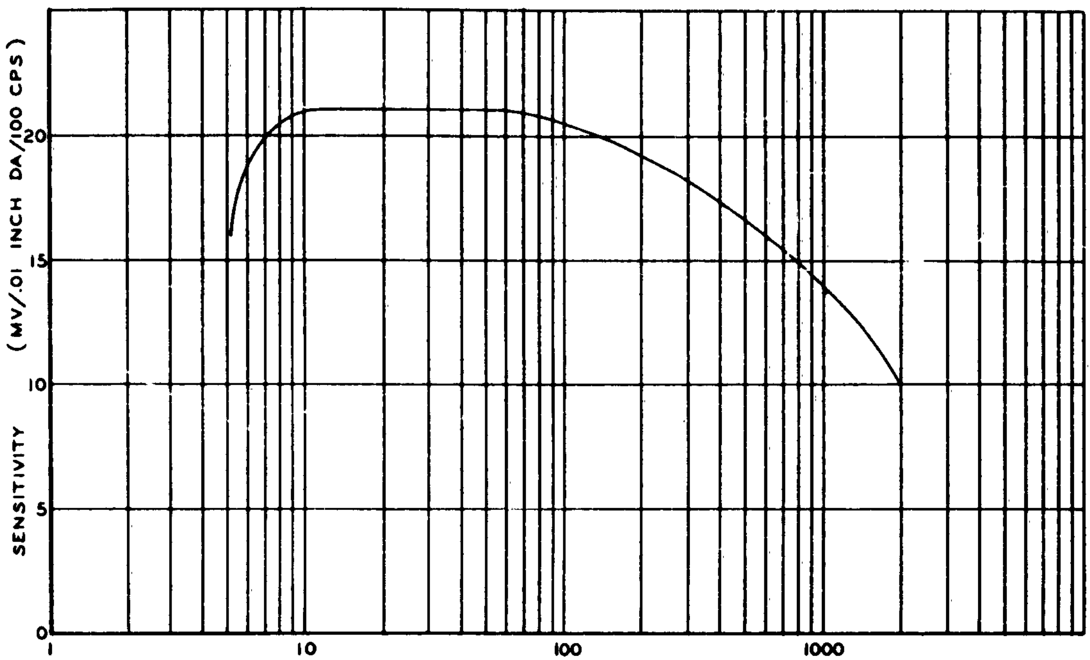

Figure 2. Graphic Presentation of Frequency Response of MB Type 124 Vibration Pickup

2. Test Procedure

A total of 31 test flights were flown during this survey. A summary of the test experiences attained is shown in Table III. The test plan was based on requirements of interested laboratories at WADD and on information obtained from USAF flight test pilots. Data were obtained during all of the normal operational configurations which the aircraft could be expected to encounter. These configurations included formation flying to evaluate the effects of one aircraft on another in close formation. It also included gunnery missions to determine the effects of the intense vibration produced by gunfire. Test conditions were also established which permitted the evaluation of such variables as altitude, indicated airspeed, engine thrust at constant airspeeds and altitudes, the effects of using the speed brakes, gear, and other control surfaces at various airspeeds. Prior to each flight, the test pilot was thoroughly briefed on the desired flight test conditions and was given the appropriate flight test data card. As soon as the desired flight test condition was achieved, the output of each of the 60 pickups was recorded in successive groups of twelve each. This was done by means of a remotely controlled selector switch. A total of 1,229 records was made during the 31 test flights. The reels of recorded data were returned to the laboratory for analysis.

TABLE III

FLIGHT CONDITIONS FOR F-101A

Code	Test Condition
01	Taxi
02	Ground Runup Clean
04	Take-off
06	Climb (Normal)
07	Cruise (Normal)
08	Cruise (Speed Brakes Extended)
09	Cruise (Gunfire)
15	Cruise (Flaps Extended)
16	Cruise (Gear Extended)
17	Cruise (Refueling Doors Extended)
21	Normal Descent (Clean)
22	Normal Descent (Speed Brakes Extended)
23	Normal Approach
24	Normal Approach (with Flaps, Gear, etc., Extended)
25	Touchdown
26	Landing Roll
27	Drag Chute
28	Fuel Doors Open
44	Ground Runup (with One or More Engines Out)
47	Climb (with Afterburner)
48	Cruise (with Afterburner - Clean)
49	Cruise (with Afterburner - Speed Brakes)
50	Cruise (with Afterburner - Flaps)
55	Cruise (Speed Brakes and Gear)
56	Cruise (with Speed, Flaps and Gear Extended)
61	Cruise (with Afterburner, Speed Brakes, Flaps and Gears Extended)
62	Formation Straight and Level - Clean without Afterburner
63	Formation Straight and Level - Clean with Afterburner

3. Data Processing

The reels of tape were edited and each 5-second record was spliced into a continuous loop and properly labeled. These records were analyzed by means of a Davies Model 510 automatic analyzer which was used in conjunction with a Davies Model 502 magnetic tape playback system. The complete playback and analysis system is shown in Figure 3.

The Model 502 magnetic tape playback system had been modified to provide playback at either 15 or 30 inches per second. The tape playback contained a servo control system which permitted playback of the tape at its originally recorded speed, within very close tolerances. During playback, the output from all fourteen tracks was fed simultaneously into the fourteen FM playback discriminators. The output signal from each of the twelve data channels was a 1 to 1 reproduction of the original analog signal.

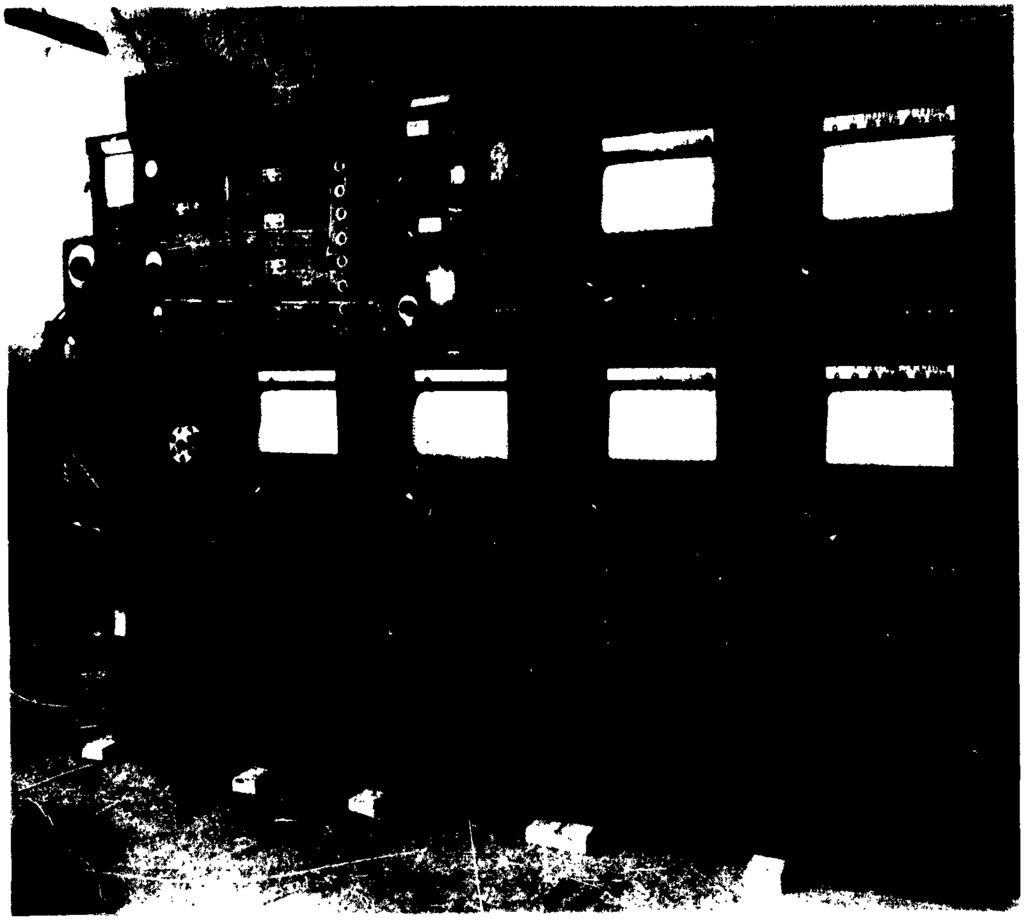

Figure 3. Automatic Tape Playback and Analysis System Equipment

An important feature of the playback system, i.e., electronic compensation, should be discussed briefly at this point. During the data recording process, the input of the number 7 track (channel) on the tape was the voltage from a very stable, crystal-controlled reference frequency oscillator which was contained within the recorder. During playback, a portion of this 10 KC signal was fed into a standard FM discriminator channel. Assuming there were no wow and flutter during playback, the output voltage from this particular discriminator (channel 7) would have been zero. Therefore, if any voltage were obtained from this channel during playback, it would have been an "error" voltage produced by wow and flutter. This "error" voltage, with its phase shifted 180°, was fed simultaneously into the output stage of each of the twelve data channels. In this manner, the extraneous voltages due to wow and flutter were eliminated from the signal output of the data channels. Prior to playback of data, each of the data channels was adjusted for optimum cancellation (approximately 40 db). Hence, an overall dynamic range of 45 db (record through playback) could be maintained consistently. Table IV contains a summary of pertinent facts pertaining to the Davies Model 502 magnetic tape playback system and the Davies Model 510 automatic wave analyzer.

TABLE IV

SPECIFICATIONS FOR DAVIES LABORATORIES
MODEL 502 MAGNETIC TAPE PLAYBACK
AND MODEL 510 AUTOMATIC ANALYZER

Frequency Range	3 cps to 2,000 cps
Frequency Accuracy	0.2 cps from 3 to 40 cps 0.5% from 40 to 2,000 cps
Input Voltage Range (2-position switch)	1.0 volt or 10 volts rms maximum
Amplitude Accuracy	5% of reading or 0.2% of full scale
Selectivity	Narrow Range - continuously variable from 1/2 to 8 cps Broad Range - continuously variable from 8 to 45 cps
Scanning Speeds, Motor Drive	Speed Range 25:1 - continuously adjustable Minimum Sweep Time - 15 minutes Maximum Sweep Time - 6 hrs. and 15 min.
Recorder Speed of Response	2 seconds for 90% full scale
Tape Speed	15 or 30 inches per second
Loop Length	Approx. 2-1/2 ft. to at least 75 ft.
Tape Width	1 and 1-3/4 inch

The Davies Model 510 automatic analyzer is a constant bandwidth heterodyne analyzer complete with a motor-driven variable frequency oscillator. The system has six separate analyzers and can simultaneously analyze six data channels. Both the oscillator scanning rate and the analyzer bandwidth are adjustable over the following limits:

(1) Scan rate 0.3 to 3.0 cps/sec

(2) Bandwidth 1 to 40 cps

The output of the six wave analyzer channels was fed into six modified Brown strip chart recorders. A continuous spectrum plot of frequency (cps) versus voltage (rms) was produced by the strip chart recorders. The chart speed was servo-controlled and could be varied from 0.08 inches per minute to 13.5 inches per minute. The voltage was plotted on a logarithmic scale, and the time required for full scale deflection, i. e., zero to one volt, was approximately two seconds. A sample analysis of a 100-cps square wave is shown in Figure 4.

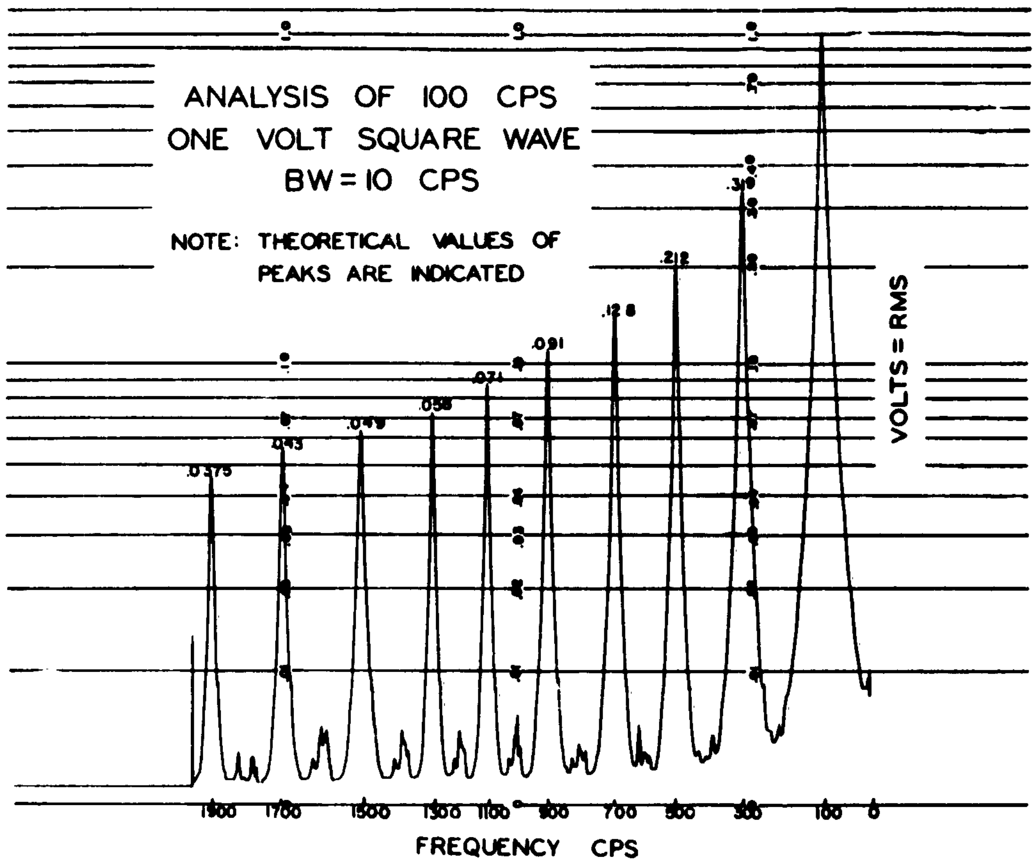

Figure 4. Graphic Presentation of Analysis of 100 cps One Volt Square Wave

In selecting the bandwidth to be used in an analysis of this type, one must consider the following: (1) the frequency resolution desired, (2) the rate of scan, (3) the length of the data sample, (4) the time available for data analysis, (5) the quantity of data to be analyzed, (6) the type of data being analyzed, and (7) the type of presentation of the completed data. Based on a consideration of these variables, a bandwidth of ten cycles per second was selected for these analyses.

Following the harmonic analysis, the Brown strip chart recordings were edited and the voltage peaks of interest were marked. Each of these peaks constitutes a data point. The corresponding values of frequency and voltage for each of these peaks were tabulated and, subsequently, punched into IBM cards. Each data point was recorded on a separate card. Then these cards were processed through the ERA 1103A computer at the rate of ninety cards per minute. Prior to processing each set or flight of data cards through the computer, a series of three sets of "master cards" was prepared and fed into the computer. These sets of "master" cards are:

(1) The "flight condition masters," which contain all of the necessary flight parameters, i.e., altitude, IAS, power, etc., associated with each of the data cards. This information is obtained from the flight test data card.

(2) The "pickup location masters" which contain the information required to identify each data point for each channel and record number, with a particular pickup.

(3) The third set of "masters," which are known as the "source and order masters," contains sufficient information to identify specific vibration frequencies with known orders of engine and propeller unbalance and also blade passage frequencies of the propeller or rotor blades, as the case may be.

As the data cards were processed, a new and complete "answer" card having the following information was produced: the computed values of double amplitude in inches, acceleration in g's, log of frequency, log of double amplitude, log of acceleration, all of the data on the original data card, and all of the appropriate data obtained from the "master" cards.

After the computations were completed, all of the data cards were arranged in the desired sequence by means of an IBM sorter. Then a multi-copy IBM listing was made of all data. These listings were used in detail studies of the data and in checking the accuracy of the completed graphs.

Automatic plotters, utilizing IBM card input, were used to plot the graphs of frequency in cycles per second versus vibratory double amplitude in inches. The plotting rate for the plotters used in these tests ranged from 30 to 60 points per minute. The three types of graphs plotted were:

(1) Summary (all test conditions) plots for each individual vibration pickup,

(2) Summary plots for each cluster (2 or 3) of pickups,

(3) Summary plots for each "structural zone."

In all three types, all of the data obtained on the 31 flights were plotted. No plots were made to indicate the effects of variables, such as power, altitude, IAS, etc. Plots of this type can be obtained upon request.

The Type 1 graphs permit a detailed study of the vibration characteristics at a particular location in the test vehicle along a single axis.

The Type 2 graphs present the overall vibration environment, measured under all test conditions, at each of the 25 test points. Generally, this includes all data obtained from the 2 to 3 pickups in each cluster.

Where the overall vibration environment for a generalized structural zone, e.g., front quarter of the fuselage, is desired, the Type 3 graphs are most useful. The structure of the test vehicle has been arbitrarily divided into nine major areas. Each of these major areas has been further subdivided into the following three categories: (1) vehicle structure, (2) rigidly mounted equipment, and (3) shock-mounted equipment. A complete listing of these "structural zones" is contained in Table V.

TABLE V

CODE FOR STRUCTURAL ZONE OF A/C

Code Nr.	Structural Zone
01	Forward Quarter of Fuselage
02	Center Half of Fuselage
03	Aft Quarter of Fuselage
04	Vert. & Horiz. Stab. Incl. Rudder & Elevators
05	Outer one-third of Wing
06	Inner two-thirds of Wing
07	Engine
08	Rigidly Mounted Equipment in Forward Quarter of Fuselage
09	Rigidly Mounted Equipment in Center Half of Fuselage
10	Rigidly Mounted Equipment in Aft Quarter of Fuselage
11	Rigidly Mounted Equipment in Vert. & Horiz. Stab. Incl. Rudder & Elevators
12	Rigidly Mounted Equipment in Outer one-third of Wing
13	Rigidly Mounted Equipment in Inner two-thirds of Wing
14	Rigidly Mounted Equipment in Engine
15	Shock Mounted Equipment in Forward Quarter of Fuselage
16	Shock Mounted Equipment in Center Half of Fuselage
17	Shock Mounted Equipment in Aft Quarter of Fuselage
18	Shock Mounted Equipment in Vert. & Horiz. Stab. Incl. Rudder & Elevators
19	Shock Mounted Equipment in Outer one-third of Wing
20	Shock Mounted Equipment in Inner two-thirds of Wing
21	Shock Mounted Equipment in Engine
22	Engine Accessory Section
23	Main Rotor Transmission Case
24	Rigidly Mounted on Engine Accessory Section
25	Rigidly Mounted on Main Rotor Transmission Case
26	Shock Mounted on Engine Accessory Section
27	Shock Mounted on Main Rotor Transmission Case

All graphs are log-log (3 x 5 cycle) plots of frequency versus double amplitude vibration. As indicated previously, the log of frequency, double amplitude, and acceleration were computed during the computational phase of data reduction. This is required to permit the automatic production of plots of frequency versus double amplitude on a log-log scale. The standard automatic plotters available will not accept linear input and then plot on a log scale. Therefore, by using the proper scale factors, the logarithms of the variables to be plotted can be adapted to any standard plotter input and the resultant graphs will be log-log plots of the original data. On log-log plots of frequency versus double amplitude, levels of vibratory acceleration appear as straight lines of constant slope. Reference values of ± 0.5, ± 1.0, ± 5.0, and ± 10.0 g have been included on all graphs. This permits simultaneous readings of double amplitude and acceleration at any given frequency. A more detailed description of the data reduction processes used to reduce the vibration data is contained in WADC TN 59-44, ASTIA Document Nr. AD-210478, dated February 1959, and titled: "Data Reduction Techniques for Flight Vibration Measurements."

4. Results

The 31 flights conducted in this survey yielded a total of 32,630 data points which were obtained from 25 separate locations within the test vehicle.

In general, the levels of vibration obtained in the very low frequency range are above those specified by Procedure XII of Specification MIL-E-5272C, whereas in the medium and higher frequency ranges the levels are considerably below those listed in the Specification.

The data obtained on the vehicle structure have only a few points (less than 1.0%) which exceed the following envelope:

5 to 8 cps	0.150 inches double amplitude
8 to 22 cps	± 0.50 g vibratory acceleration
22 to 70 cps	0.020 inches double amplitude
70 to 500 cps	± 5.00 g vibratory acceleration

This is also true for the engine and engine accessory section; however, in the case of the wing tip and the horizontal and vertical control surfaces, the low frequency vibration is considerably above (up to 0.500 inches double amplitude) the level required by Procedure XII of Specification MIL-E-5272C. As expected, this large amplitude, low-frequency vibration is due to the buffet and aerodynamic turbulence produced by high speed flight.

The frequency region in which the various sources are predominant, generally, is dependent on either the structural zone or the frequency range under consideration. Since this is the case and the structural zone plots represent a convenient method of determining the vibration environment in a given area within the vehicle, the detailed discussions of the data are based on the structural zones. The data were plotted in this manner and are shown in Figures 5 through 16.

The large amplitude, low-frequency vibration measured throughout the vehicle can be attributed, for the most part, to high speed flight through turbulent air. A considerably smaller portion of these data points was produced by taxi, takeoff, and landing.

Another characteristic displayed, in general, by the data is the scarcity of data points in the 15 to 25 cps frequency band. This is an important point for consideration when the problem arises of choosing the optimum resonant frequency range for vibration isolators to be used on the F-101. It should be noted that this same characteristic has been detected on other high performance jet aircraft.

For the most part, the effects of gunfire on the structural vibration levels can be considered negligible. Vibration produced by gunfire was detected only in the forward section of the vehicle in the vicinity of the guns. The average levels of this vibration seldom exceeded ± 0.5 g. The highest levels of gunfire-induced vibration were measured on the instrument panel where, in a few cases, the levels approached ± 1.0 g.

The vibration measured on the wings, outer fuselage structure, tail surfaces, and engine was, for the most part, of the discrete frequency type. This can be attributed, in part, to the structure responding at its inherent resonances to the relatively broad band forcing functions, i. e., aerodynamic noise and jet exhaust. Other discrete frequencies were produced by mechanical unbalance in rotating items, i. e., engines, alternators, and constant speed drive devices. The vibration encountered on the internal structure of the fuselage was, generally, of a much lower level and was not characterized by discrete frequencies.

The cluster of data points in the frequency range of 70 to 100 cps is due to the first order vibration produced by unbalance in the low-speed turbine of the engine. The concentrations at 140 to 160 cps, 280 to 320 cps, and 420 to 480 cps are due to the first, second, and third order vibrations produced by unbalance in the high speed rotor of the engine. The concentration in the 40 to 60 cps band is due to the vibration produced by the hydraulic pump attached to the engine accessory section. The very sharply defined concentration of data points at 100 cps is due to the first order of vibration produced by the mechanical unbalance in the alternator and constant speed drive unit which operates at a closely regulated speed of 6,000 rpm. Most of these concentrations were detected in some degree at all of the following locations: (1) on the engine, Figure 11, (2) on rigidly mounted equipment in the engine accessory section, Figure 16, (3) on the engine accessory section, Figure 15, (4) on the forward quarter of the fuselage, Figure 5, (5) throughout the center half of the fuselage, Figure 6, and, to a lesser degree, (6) on the aft quarter of the fuselage, Figure 7.

With regard to the aft quarter of the fuselage, see Figure 7, several concentrations of data were encountered which could not be related directly to the engine or any of its associated components and/or accessories. These concentrations occurred in the following frequency ranges: (1) 170 to 200 cps, (2) 210 to 250 cps, (3) 270 to 300 cps, and (4) 320 to 400 cps. Therefore, it must be assumed that these frequencies are a result of the aircraft structure responding, at its inherent resonances, to the complex forcing functions, i. e., aerodynamic noise and jet exhaust stream. In the case of the horizontal and vertical control surfaces and the wing tip, see Figures 8 and 9, there are similar concentrations of data at certain discrete frequencies, i. e., 50 to 60 cps, 75 to 100 cps, and 340 to 380 cps. However, a large portion of the data appears to have a rather random appearance and cannot be associated with any particular frequency.

The vibration measured on both rigidly mounted and shock-mounted equipment (see Figures 12, 13, 14, and 16) indicated, generally, considerable attenuation of the applied vibration in the higher frequency range (above 50 cps). This was especially true of the shock-mounted equipment. This is to be expected since the isolation characteristics of the shock mounts are considerably superior to those obtained with the relatively flexible mounting structure of the rigidly mounted equipment. With the exception of the rigidly mounted equipment on the engine accessory section (the alternator) which is a source of vibration, the level of vibration on rigidly mounted equipment seldom exceeds ± 1 g. In the case of the shock-mounted equipment, the upper limit is generally less than 0.5 g.

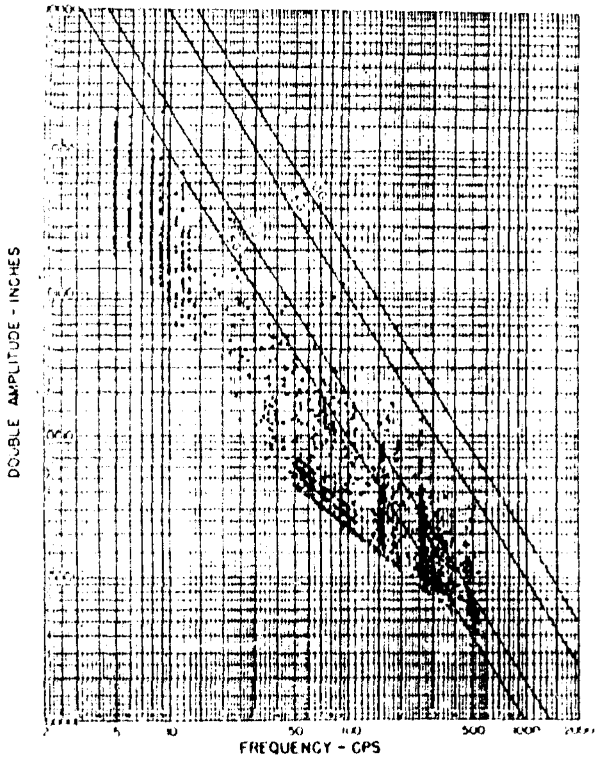

Figure 5. LOCATION FORWARD QUARTER OF FUSELAGE

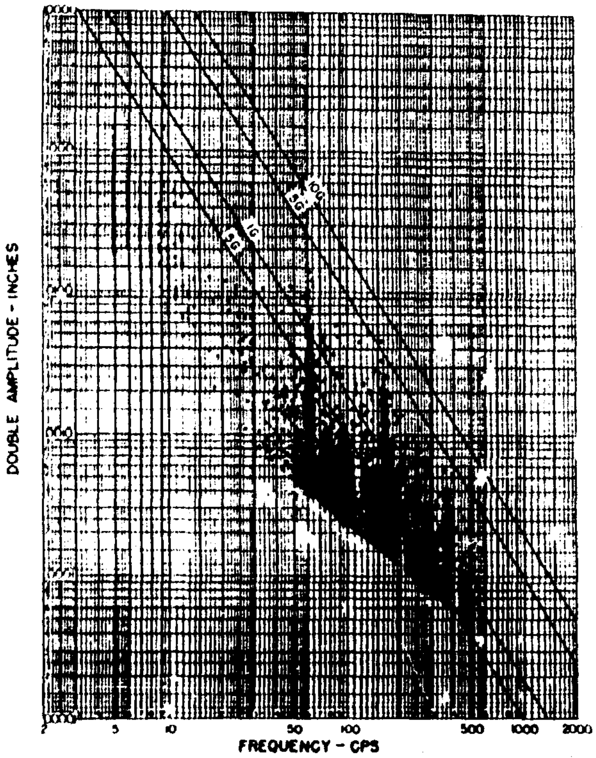

Figure 6. LOCATION CENTER HALF OF FUSELAGE

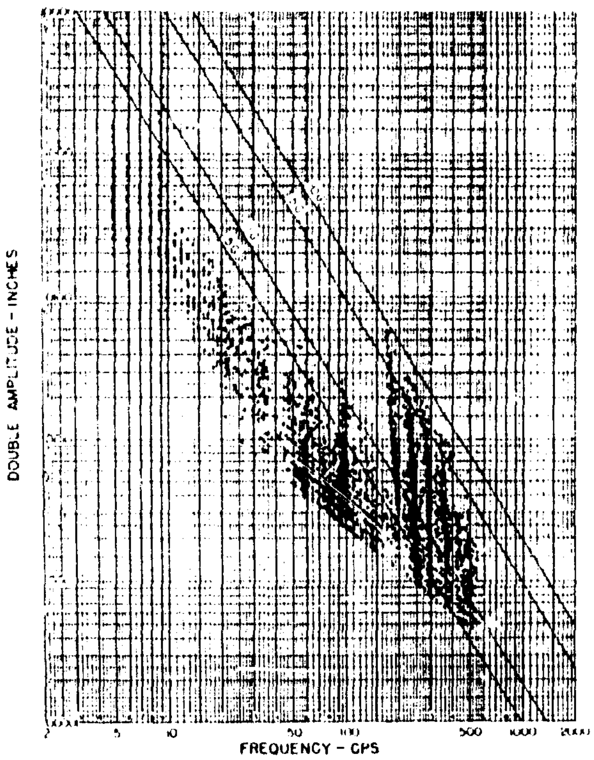

Figure 7. LOCATION AFT QUARTER OF FUSELAGE

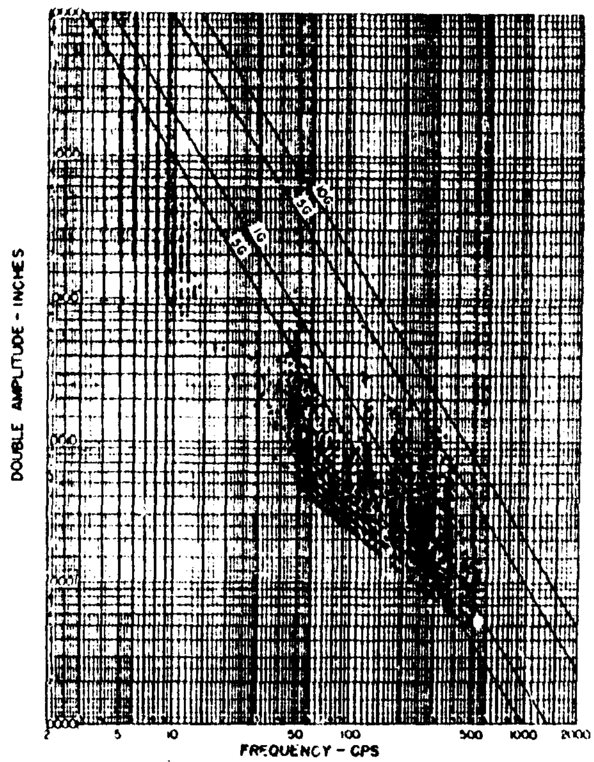

Figure 8. LOCATION VERT & HORIZ STABILIZER

Figures 5 to 8. Summary Plots for Structural Zones

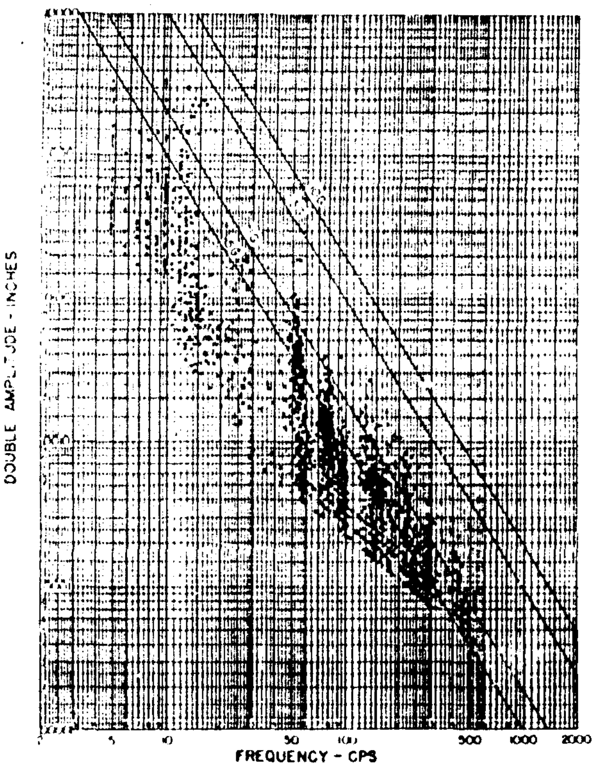

Figure 9. LOCATION OUTER ONE-THIRD OF WING

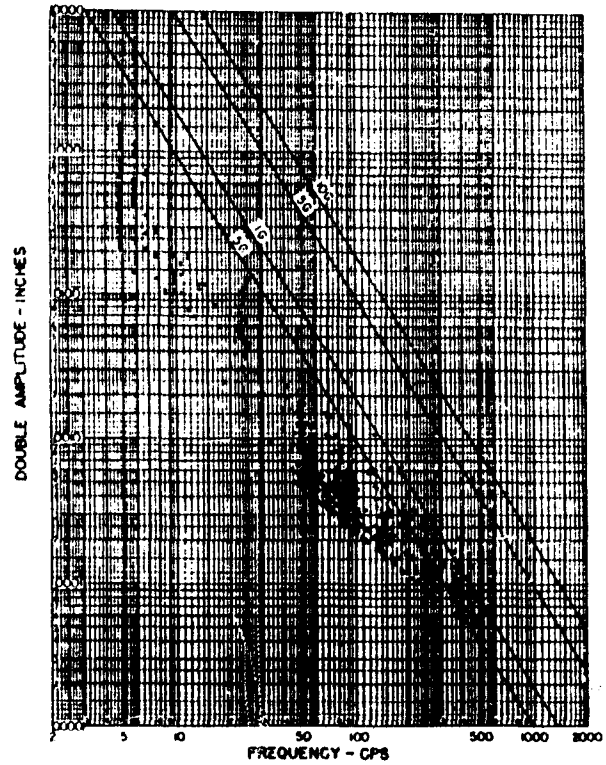

Figure 10. LOCATION INNER TWO-THIRDS OF WING

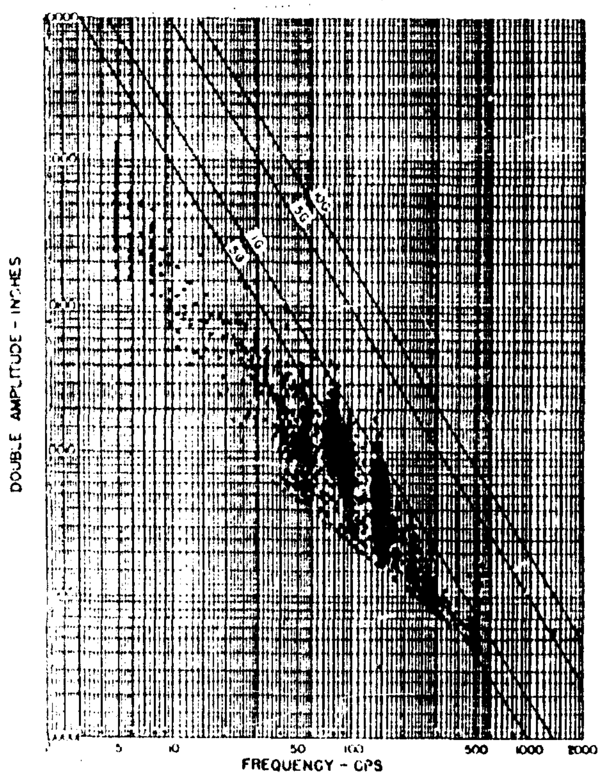

Figure 11. LOCATION ENGINE

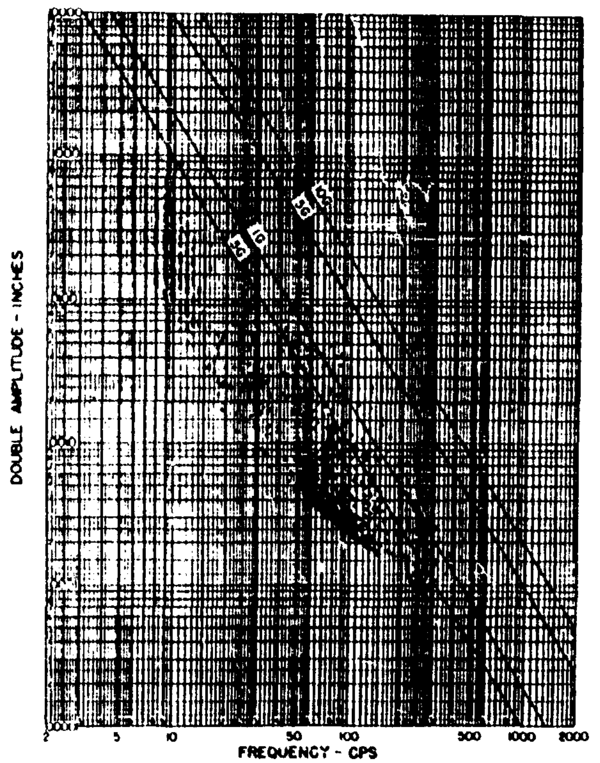

Figure 12. LOCATION RIGIDLY MOUNTED EQUIPMENT IN FORWARD QUARTER OF FUSELAGE

Figures 9 to 12. Summary Plots for Structural Zones

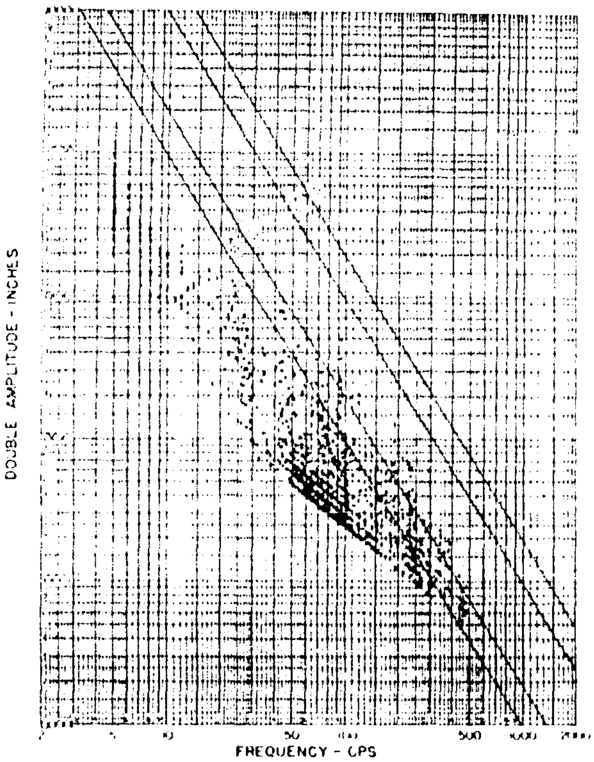

Figure 13. LOCATION RIGIDLY MOUNTED EQUIPMENT IN CENTER HALF OF FUSELAGE

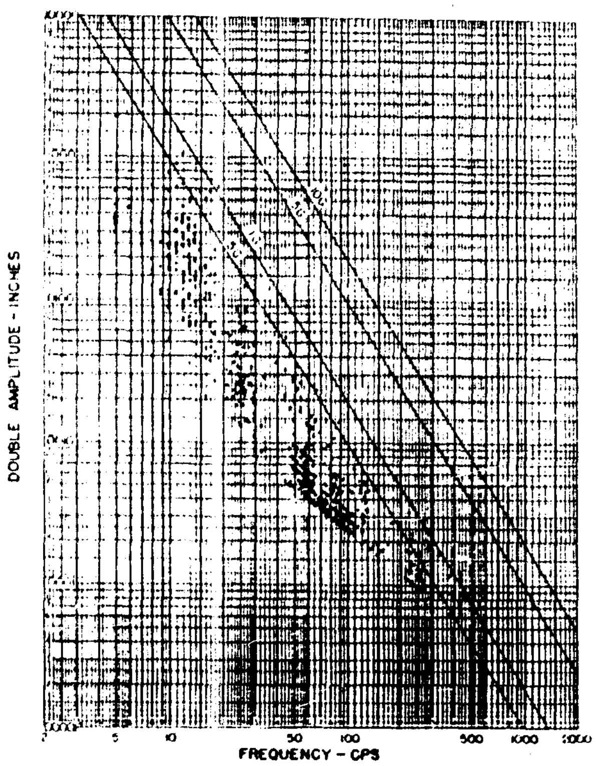

Figure 14. LOCATION SHOCK MOUNTED EQUIPMENT IN FORWARD QUARTER OF FUSELAGE

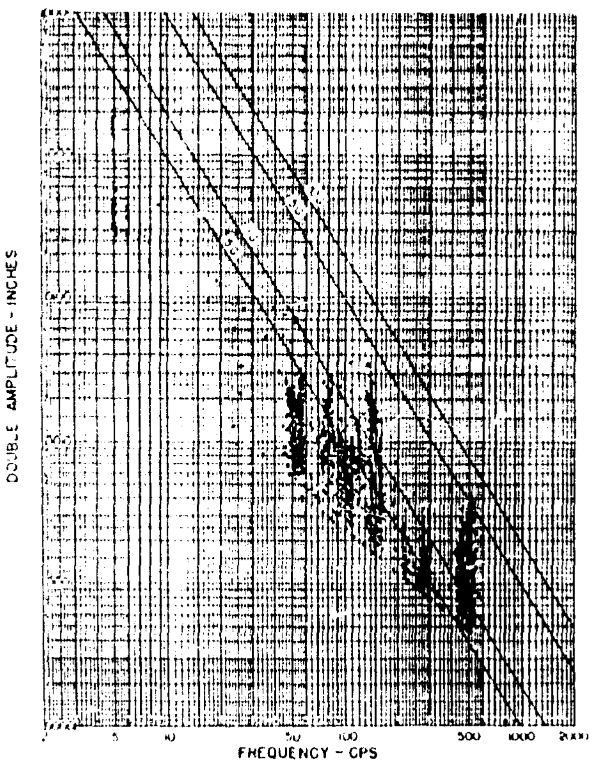

Figure 15. LOCATION ENGINE ACCESSORY SECTION

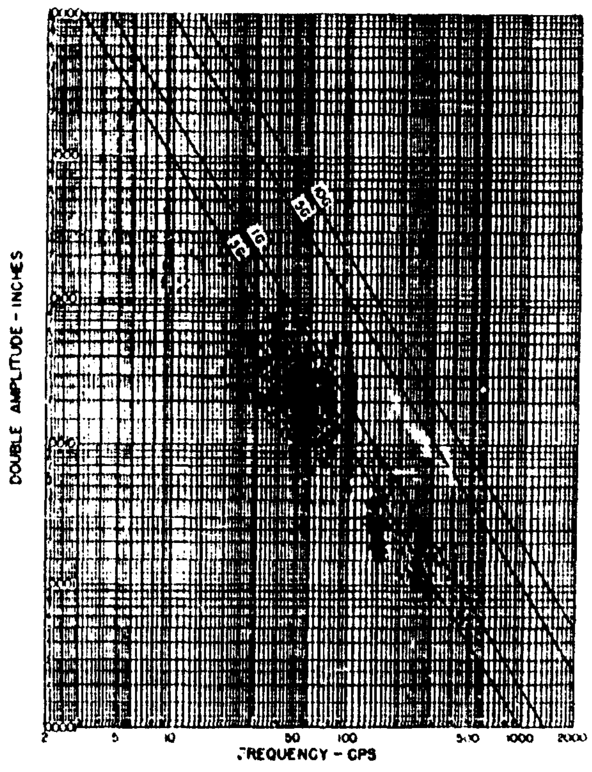

Figure 16. LOCATION RIGIDLY MOUNTED IN ENGINE ACCESSORY SECTION

Figures 13 to 16. Summary Plots for Structural Zones

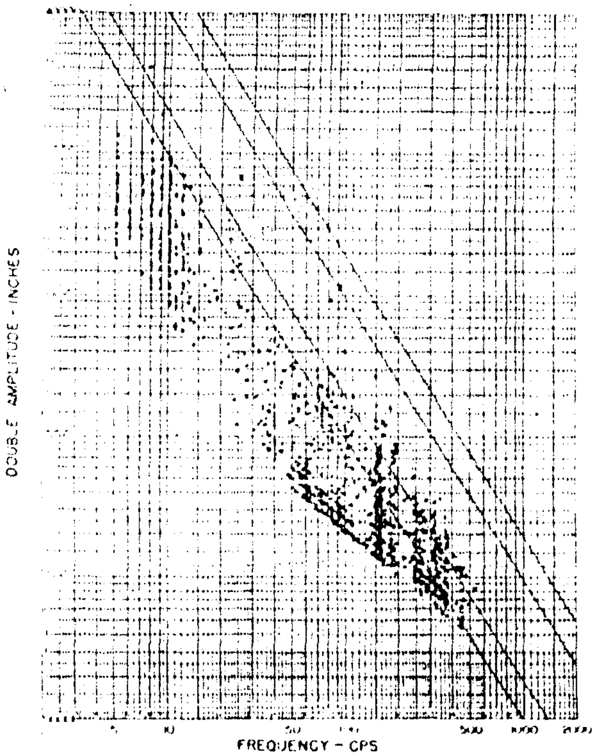

Figure 17. DIRECTION VERT -•, LAT -•, F/A -•
LOCATION STRUCTURE AT BASE OF RADAR ANTENNA F S 143

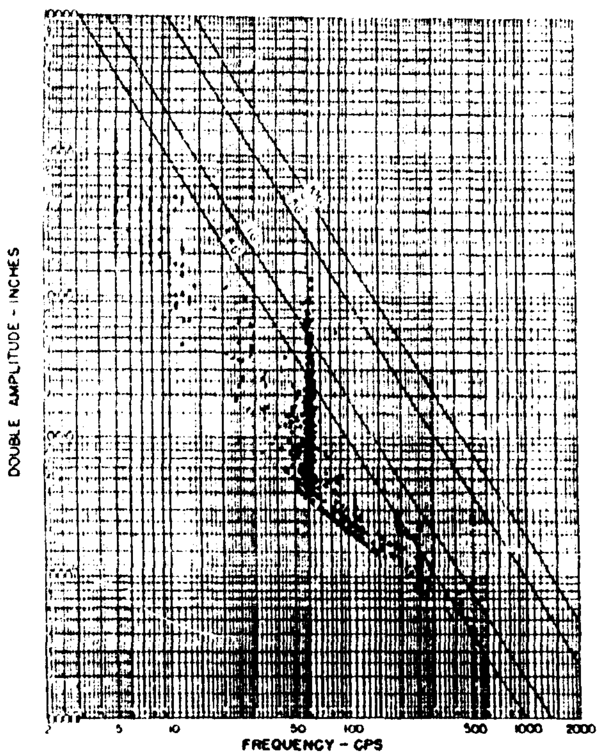

Figure 18. DIRECTION VERT -•, LAT -•, F/A -•
LOCATION STRUCTURE OF HYDRAULIC PANEL ON RT SIDE OF FUSELAGE F S 378

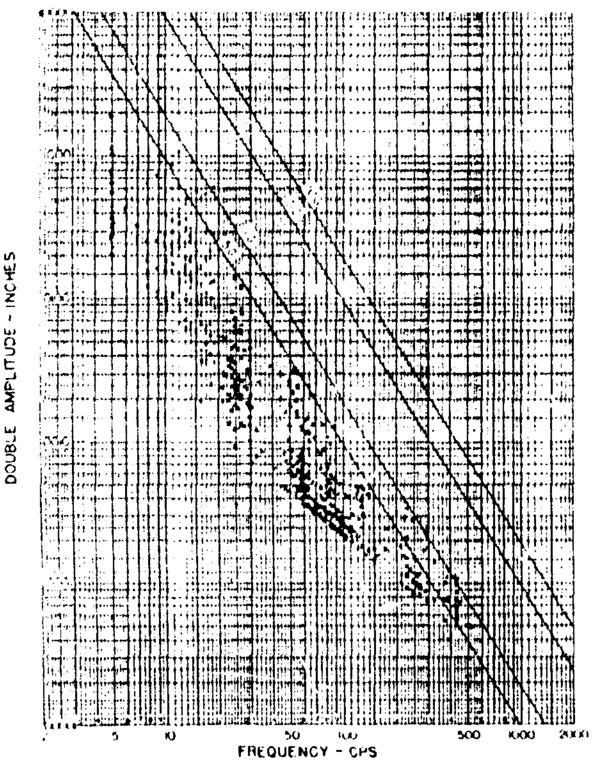

Figure 19. DIRECTION VERT -•, LAT -•, F/A -•
LOCATION SHOCKMOUTED EQUIPMENT RACK IN NOSE SECTION F S 185

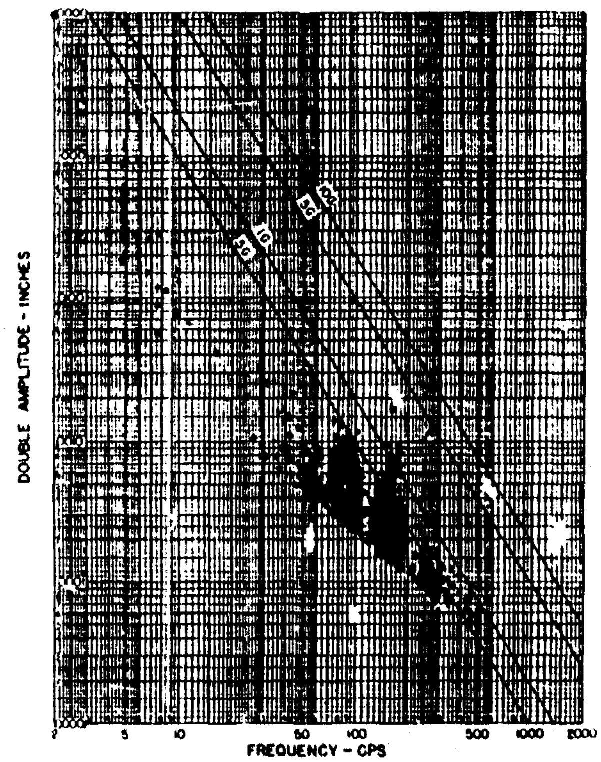

Figure 20. DIRECTION LAT -•, F/A -•, VERT -•
LOCATION STRUCTURE OF ENGINE NACELLE (CENTER) - STA. 484

Figures 17 to 20. Summary Plots for Clusters of Two or Three Pickups

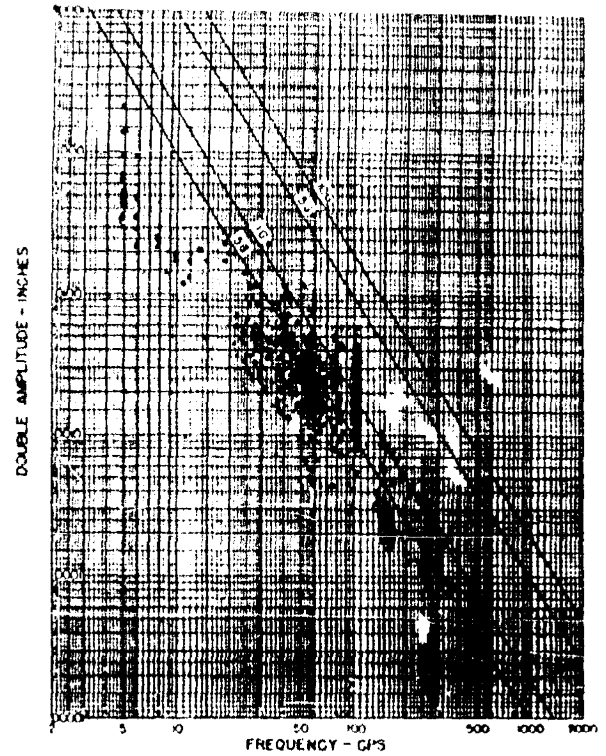

Figure 21. DIRECTION VERT --, LAT --
LOCATION BRUSH BAND SECTION OF 30KVA 6E ALTERNATOR - STA 566

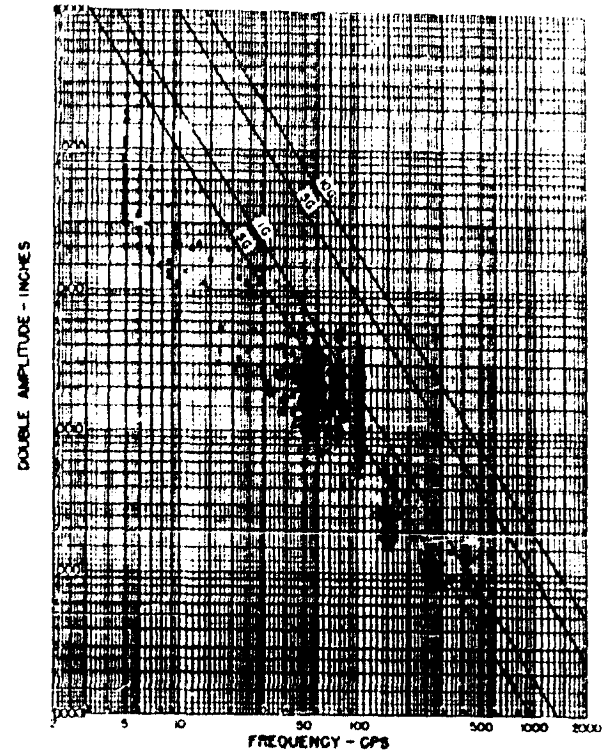

Figure 22. DIRECTION VERT --, LAT --
LOCATION SUNSTRAND CONSTANT SPEED DRIVE FOR 30KVA ALTERNATOR - STA 566

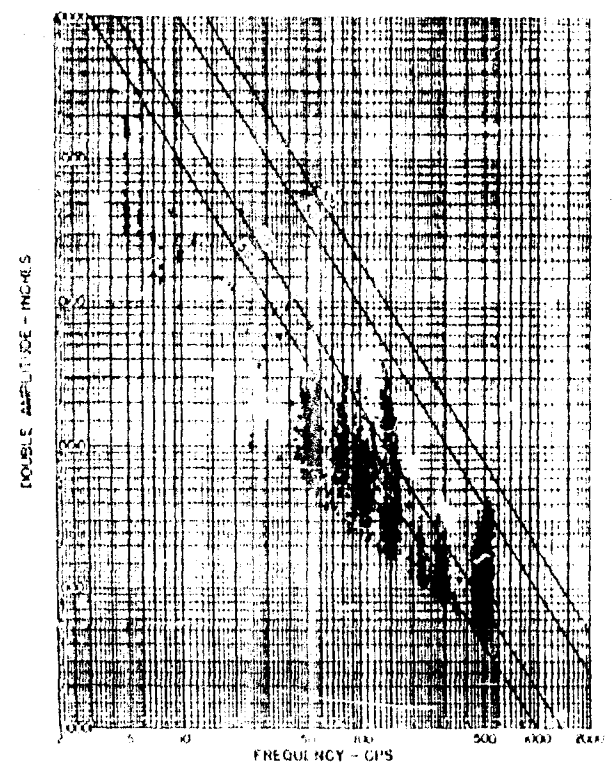

Figure 23. DIRECTION LAT -, VERT -
LOCATION FWD END OF ACCESSORY SECTION OF J-57-P13 ENGINE - STA 566

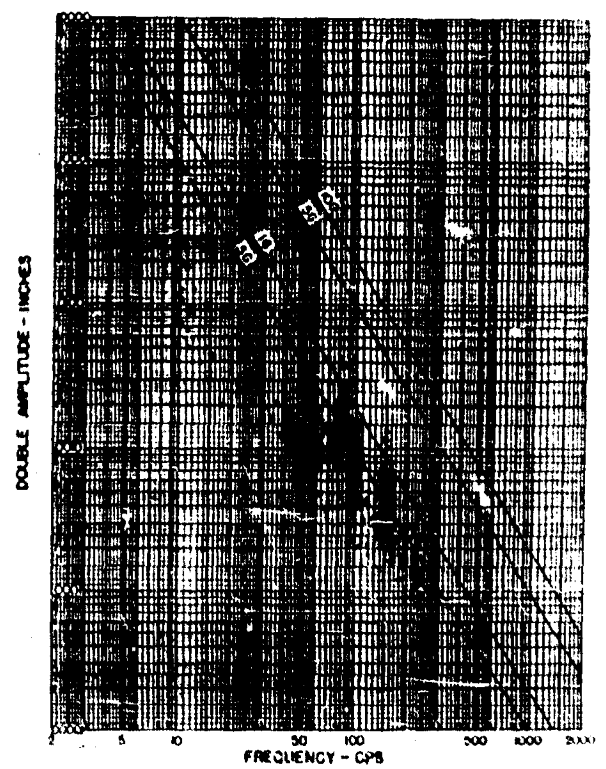

Figure 24. DIRECTION VERT -, LAT -
LOCATION FWD END OF COMPRESSOR SECTION OF J-57 P13 ENGINE

Figures 21 to 24. Summary Plots for Clusters of Two or Three Pickups

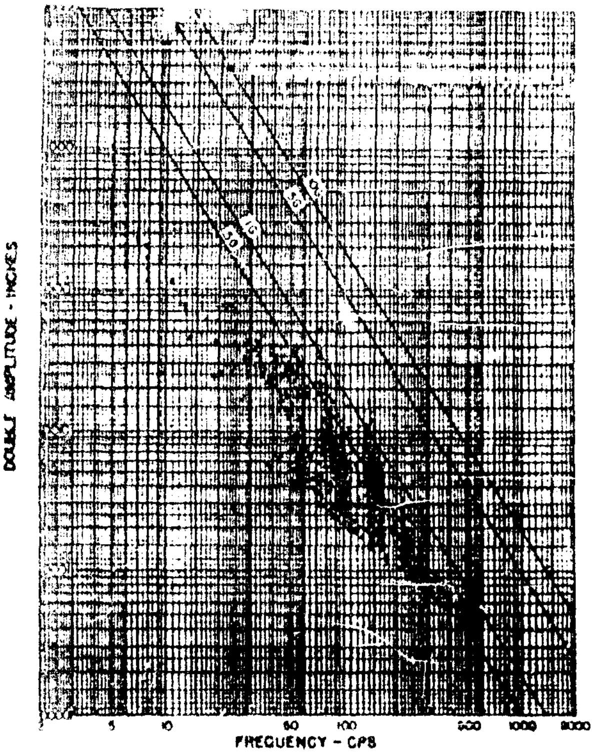

Figure 25. DIRECTION VERT-+, LAT-+
LOCATION NOZZLE SECTION OF J-57-13 ENGINE F.S. 548

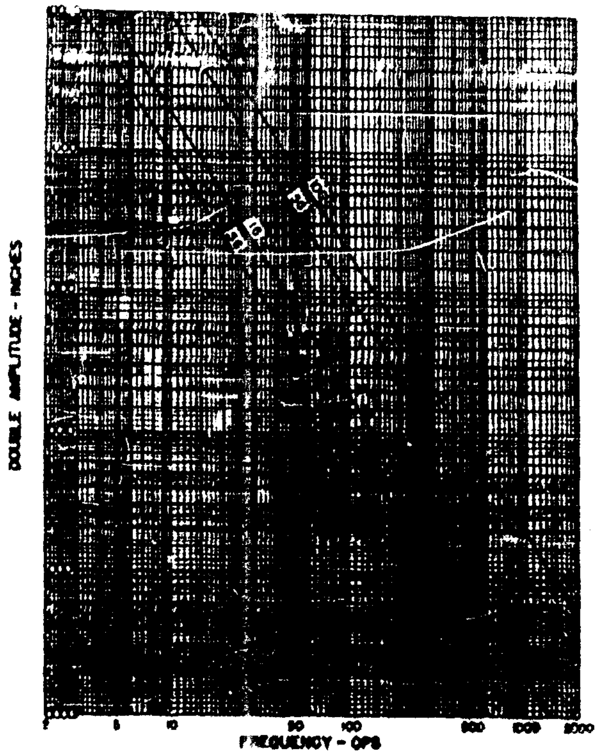

Figure 26. DIRECTION VERT-+, LAT-+, F/A-+
LOCATION STRUCTURE OF FWD. ELECTRONIC COMPARTMENT F.S. 236

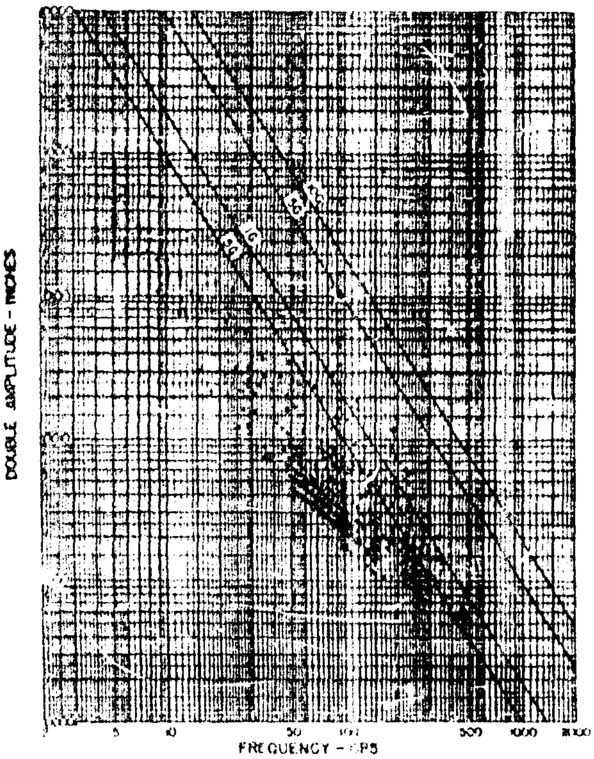

Figure 27. DIRECTION VERT-+, LAT-+, F/A-+
LOCATION STRUCTURE OF RADIO COMPARTMENT F.S. 290

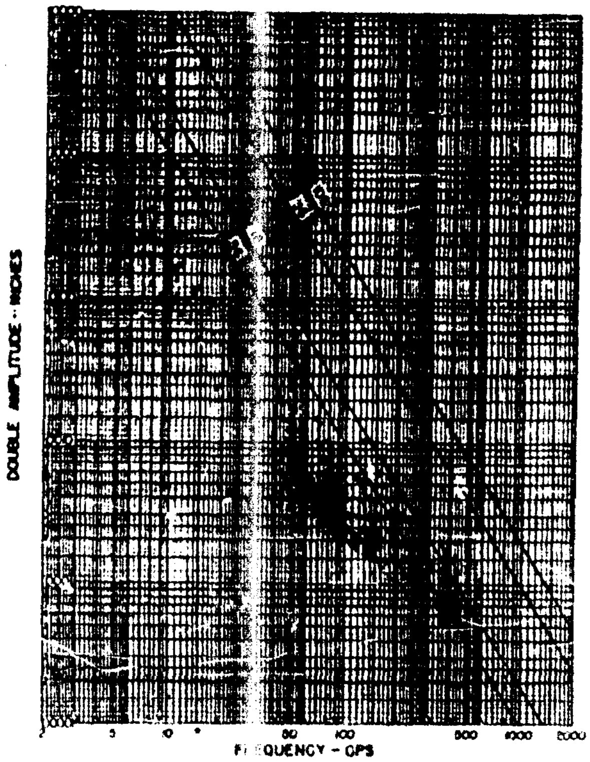

Figure 28. DIRECTION VERT-+, LAT-+, F/A-+
LOCATION STRUCTURE OF RT WHEEL WELL F.S. 546

Figures 25 to 28. Summary Plots for Clusters of Two or Three Pickups

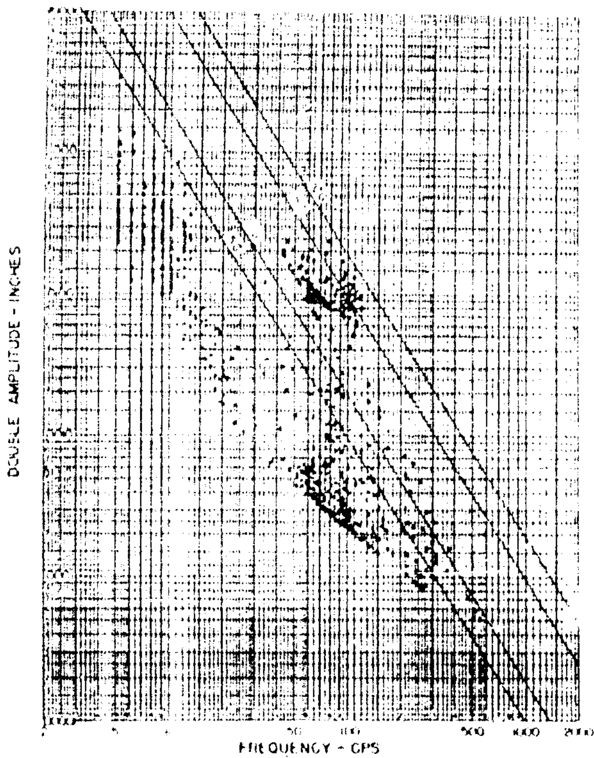

Figure 29.

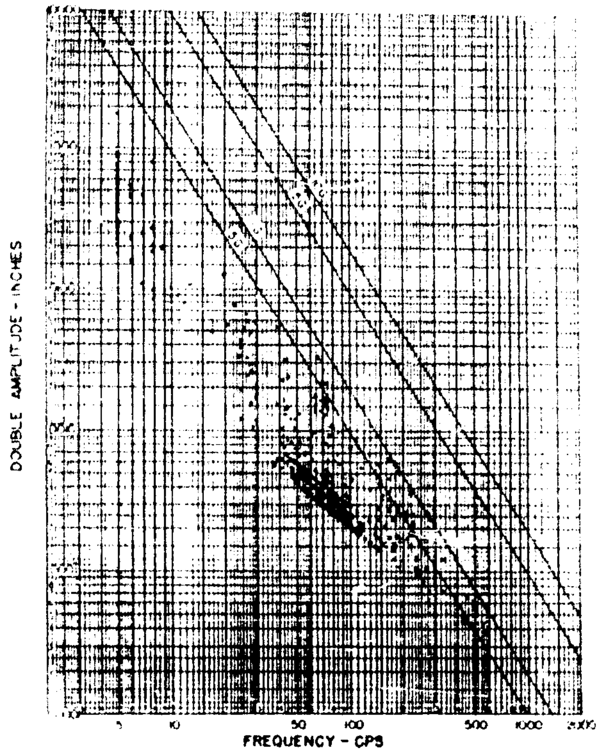

Figure 30. DIRECTION VERT
LOCATION ELECTRONIC EQUIPMENT COMPARTMENT

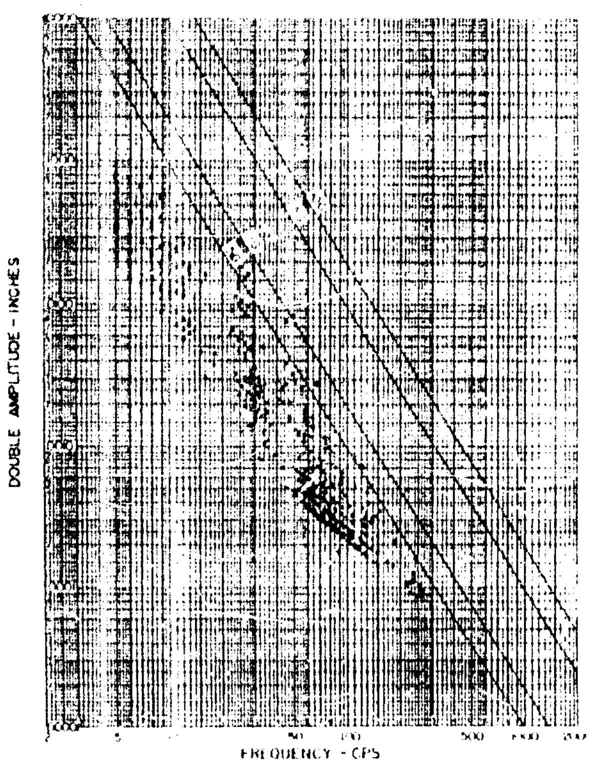

Figure 31. LOCATION INSTRUMENT PANEL

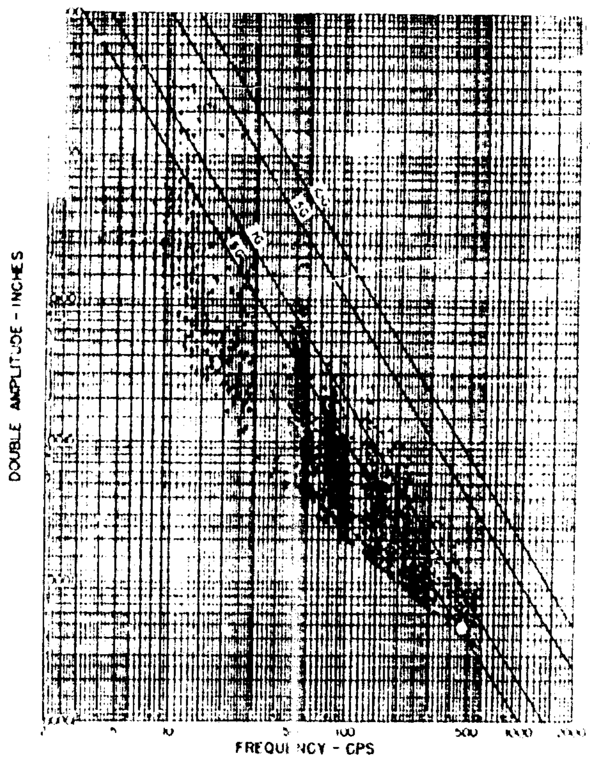

Figure 32. LOCATION RT WINGTIP

Figure 29 to 32. Summary Plots for Clusters of Two or Three Pickups

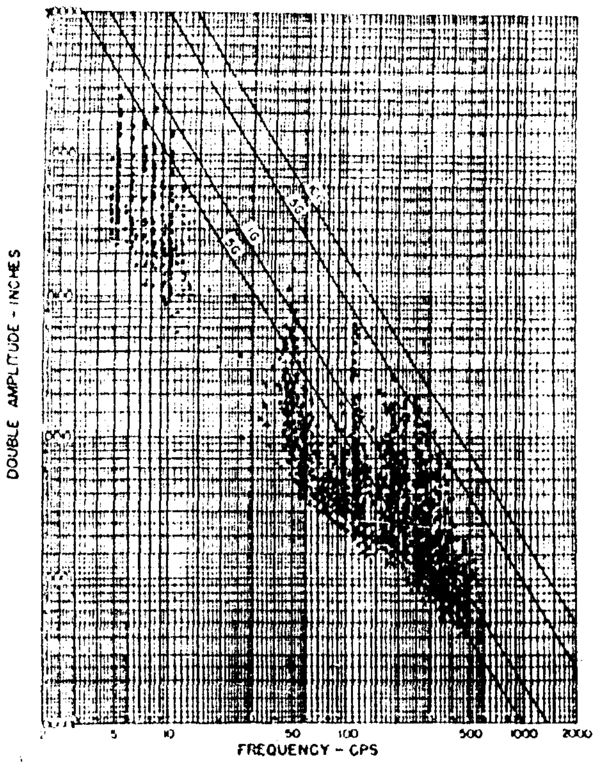

Figure 33.

DIRECTION VERT •, LAT •, F/A •
LOCATION STRUCTURE OF VERTICAL FIN F S 783

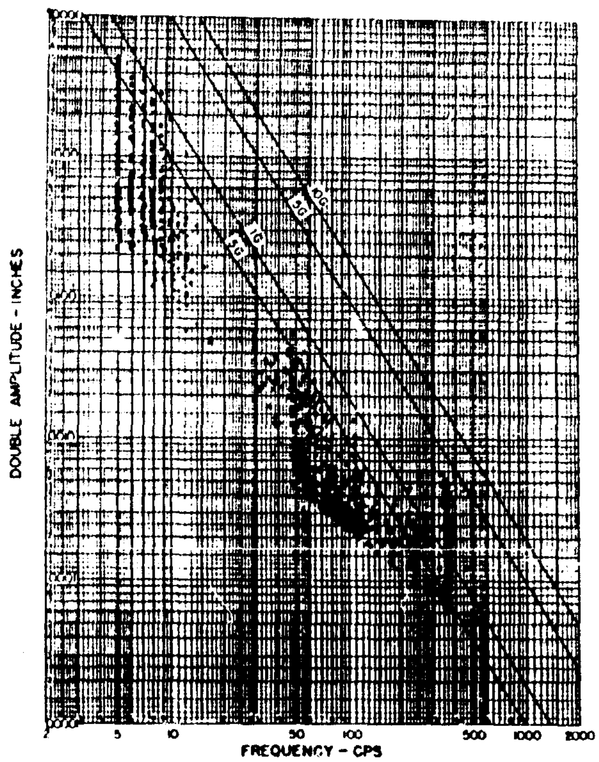

Figure 34.

DIRECTION VERT •, LAT •, F/A •
LOCATION STABILATOR ACTUATOR PLATE F S 814

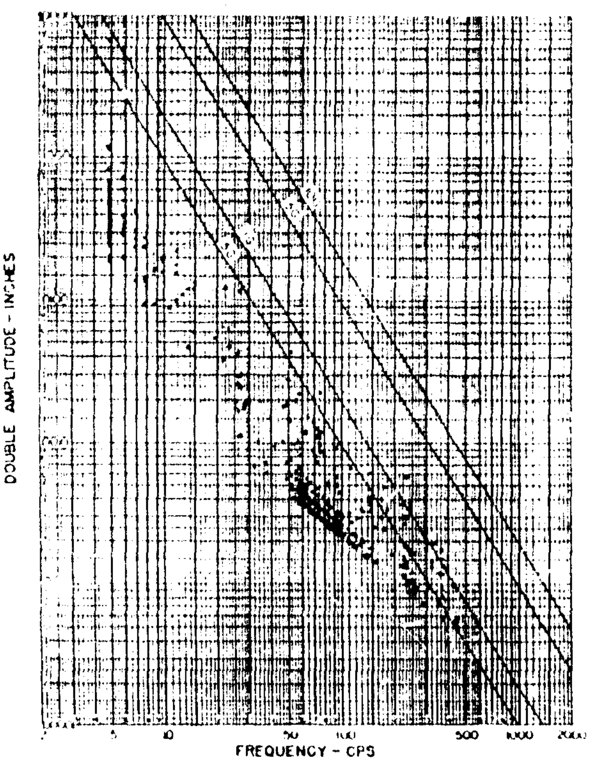

Figure 35.

DIRECTION VERT •, LAT •, F/A •
LOCATION PILOTS SEAT RAIL F S 286

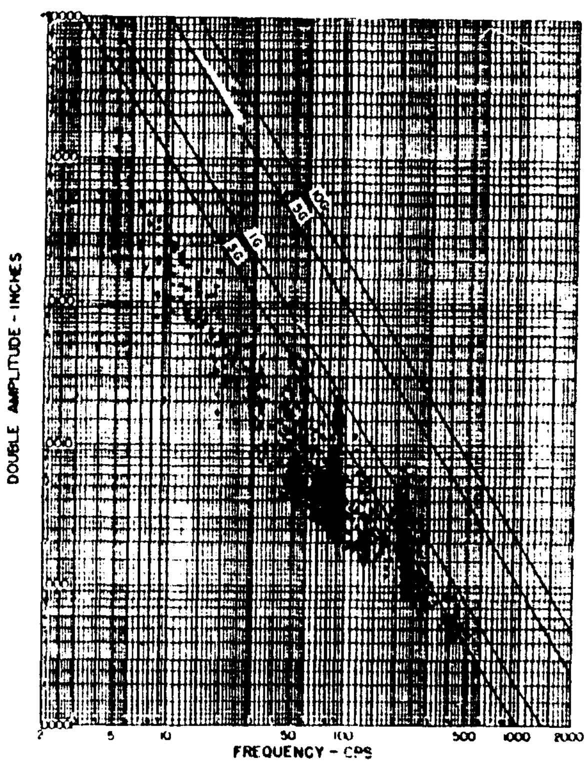

Figure 36.

DIRECTION VERT •, LAT •, F/A •
LOCATION AFT SECTION STRUCTURE
RT SIDE F S 692

Figures 33 to 36. Summary Plots for Clusters of Two or Three Pickups

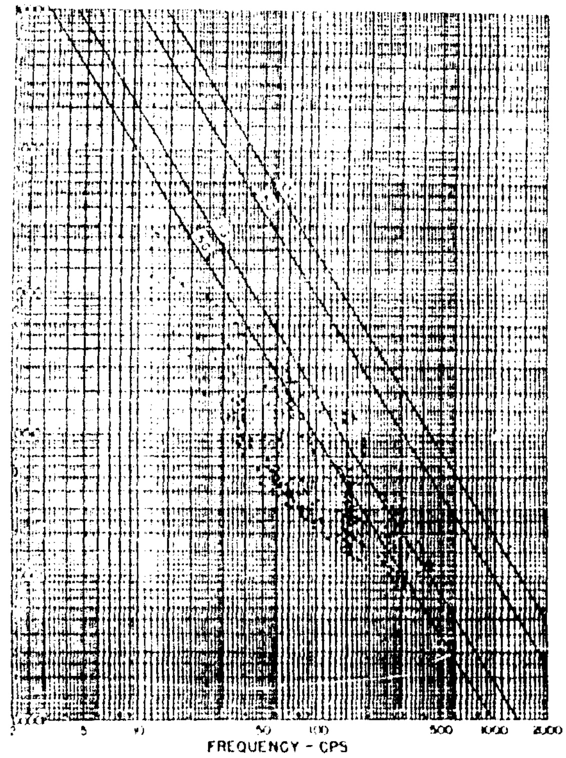

Figure 37.

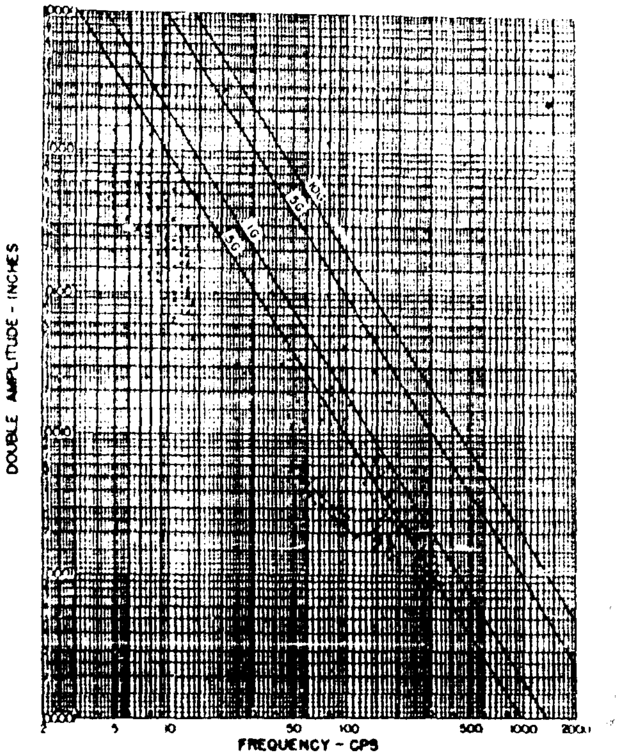

Figure 38. DIRECTION LAT
LOCATION STRUCTURE AT BASE OF RADAR ANTENNA

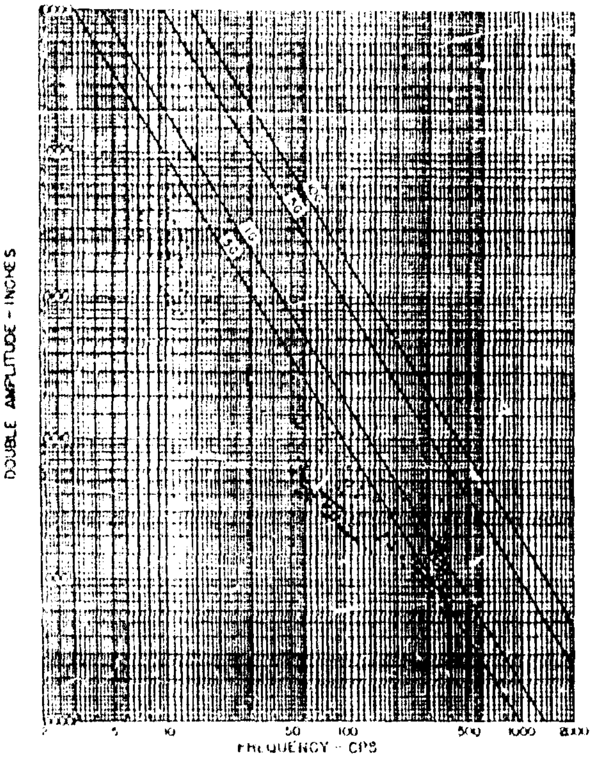

Figure 39.

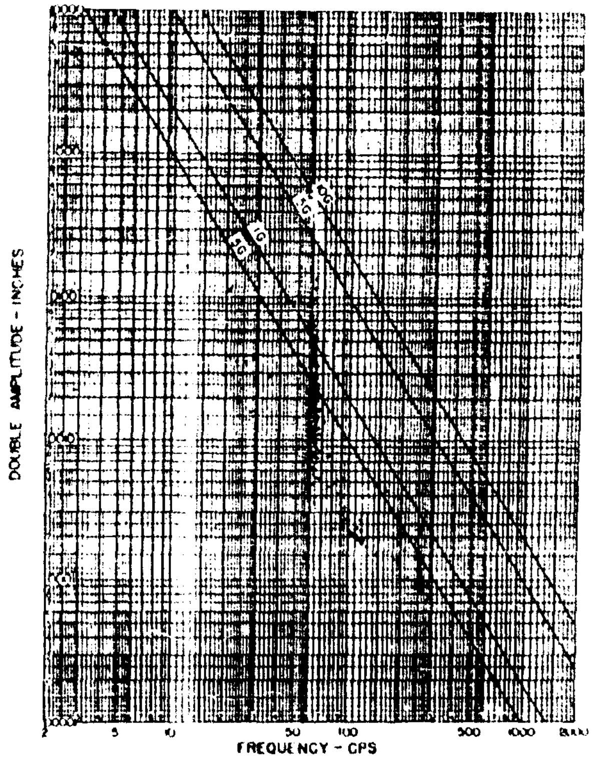

Figure 40. LOCATION STRUCTURE
OF FUSELAGE F.S. 378

Figures 37 to 40. Summary Plots for Individual Vibration Pickups

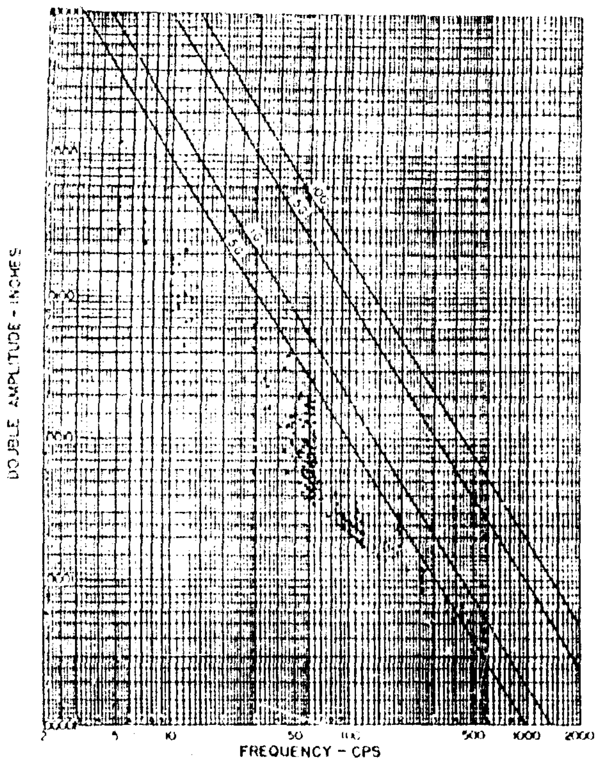

Figure 41. DIRECTION LAT
LOCATION STRUCTURE OF HYDRAULIC PANEL ON RT SIDE OF FUSELAGE F.S. 378

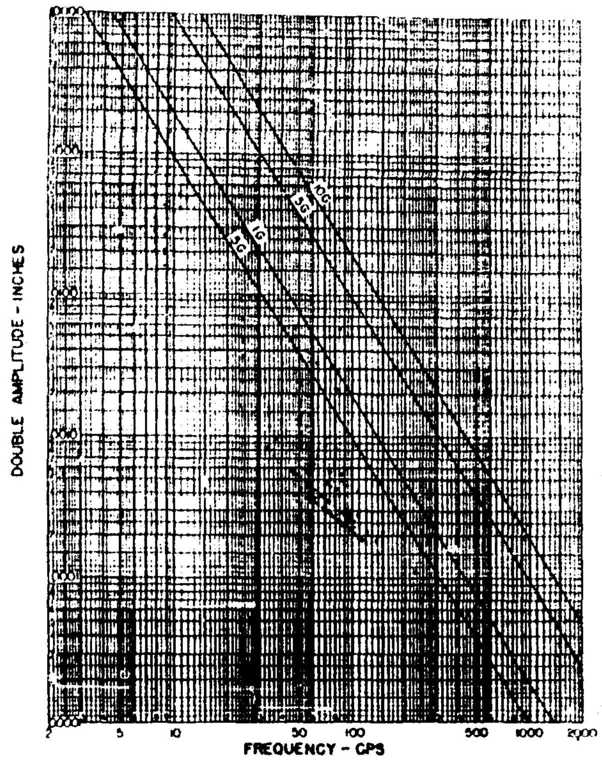

Figure 42. DIRECTION VERT
LOCATION STRUCTURE OF HYDRAULIC PANEL ON RT SIDE OF FUSELAGE F.S. 378

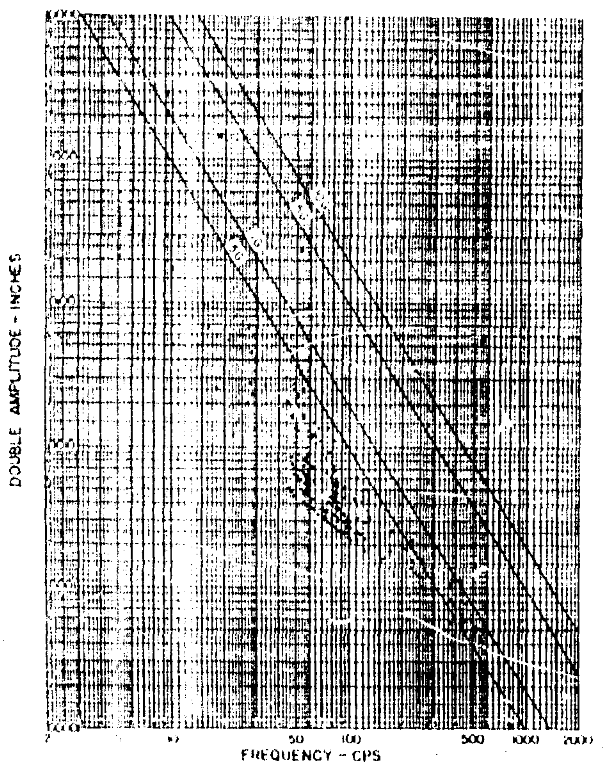

Figure 43. DIRECTION F/A
LOCATION SHOCKMOUNTED EQUIPMENT RACK IN NOSE SECTION F.S. 185

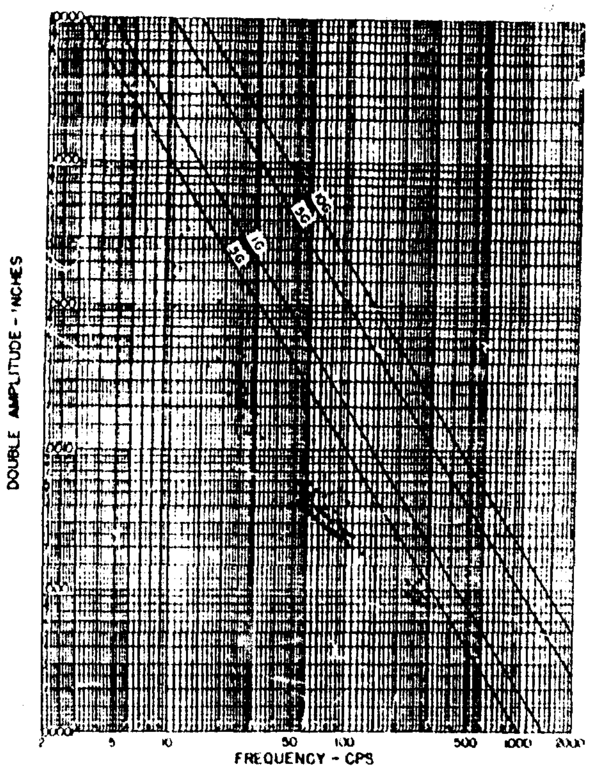

Figure 44. DIRECTION LAT
LOCATION SHOCKMOUNTED EQUIPMENT RACK IN NOSE SECTION F.S. 185

Figures 41 to 44. Summary Plots for Individual Vibration Pickups

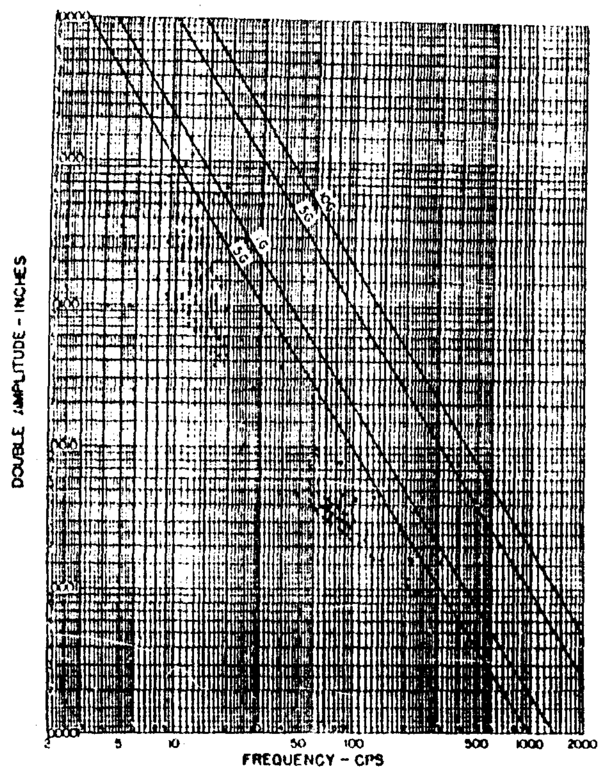

Figure 45. DIRECTION VERT
LOCATION SHOCKMOUNTED EQUIPMENT RACK IN NOSE SECTION F S 105

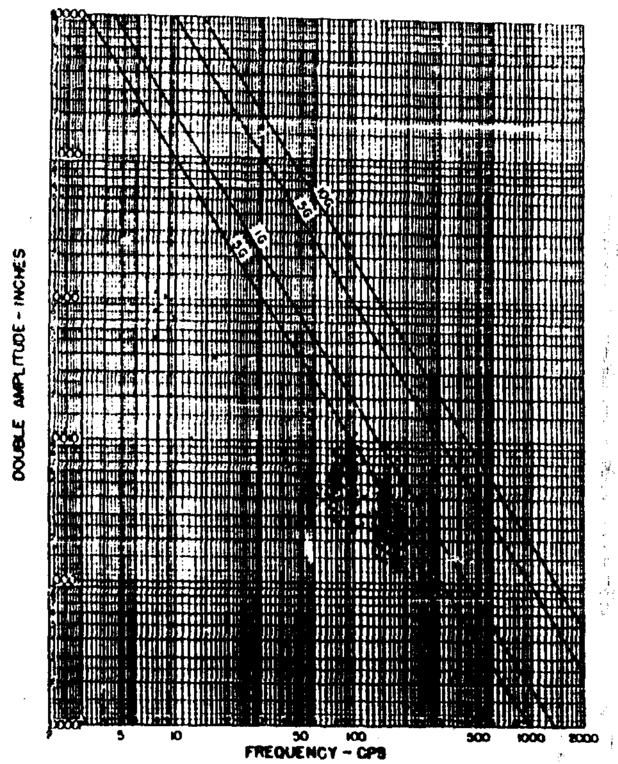

Figure 46. DIRECTION LAT
LOCATION STRUCTURE OF ENGINE NACELLE (CENTER) F S 484

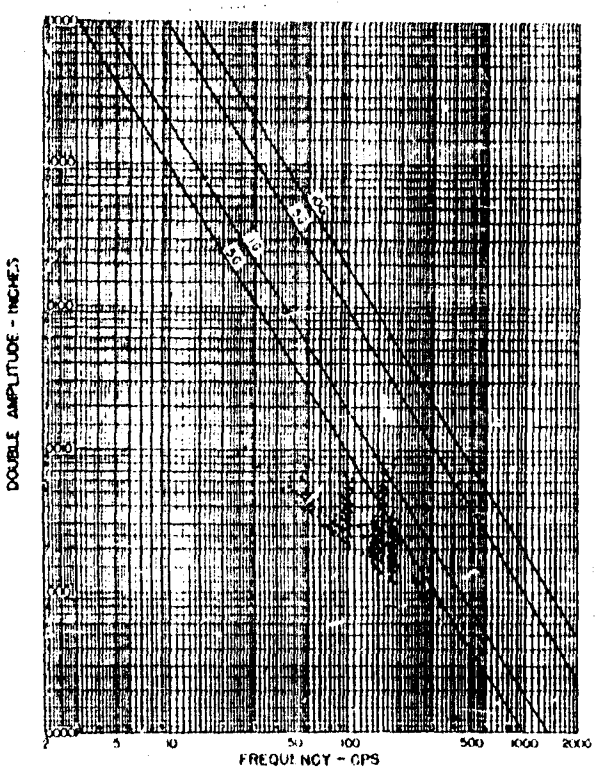

Figure 47. DIRECTION F/A
LOCATION STRUCTURE OF ENGINE NACELLE (CENTER) F S 484

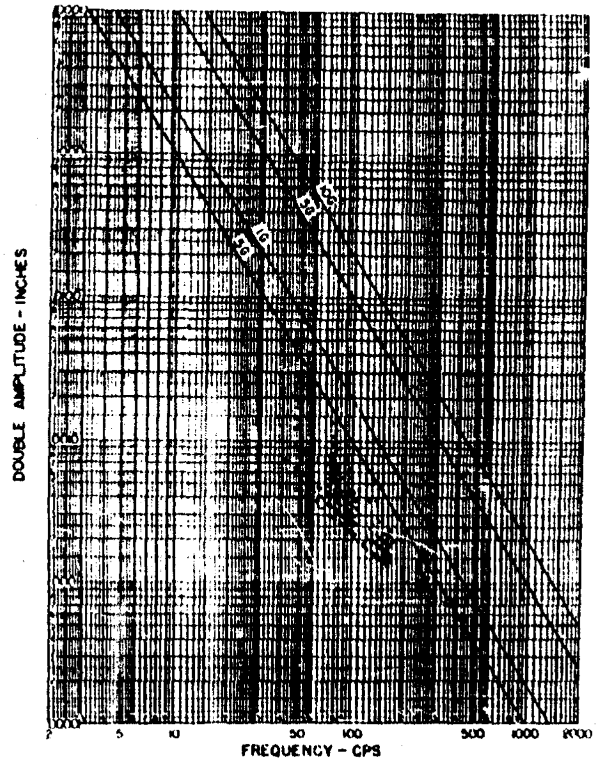

Figure 48. DIRECTION VERT
LOCATION STRUCTURE OF ENGINE NACELLE (CENTER) F S 484

Figures 45 to 48. Summary Plots for Individual Vibration Pickups

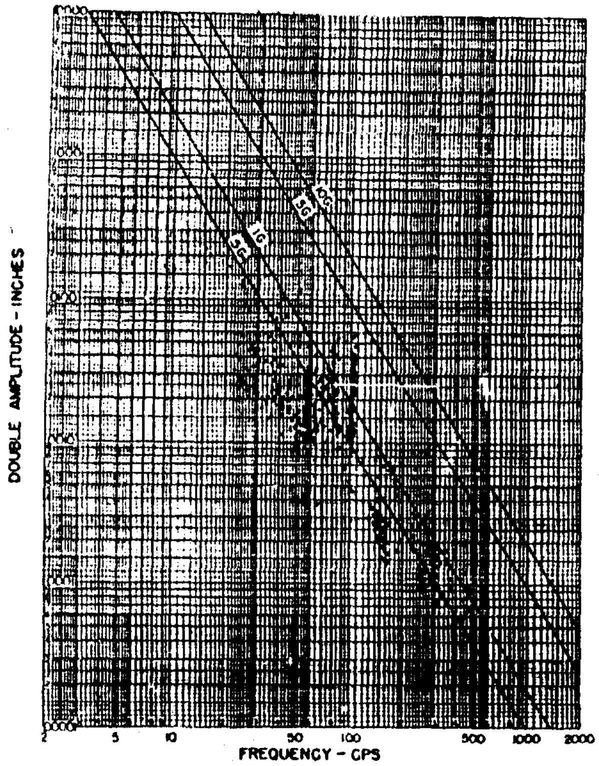

Figure 49. DIRECTION VERT
LOCATION BRUSH BAND SECTION OF 30KVA G.E. ALTERNATOR F.S. 568

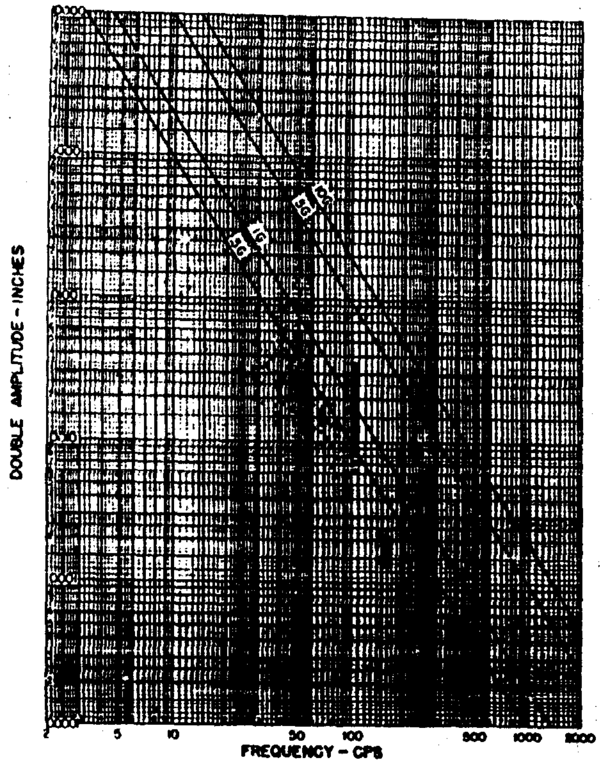

Figure 50. DIRECTION LAT
LOCATION BRUSH BAND SECTION OF 30KVA G.E. ALTERNATOR F.S. 568

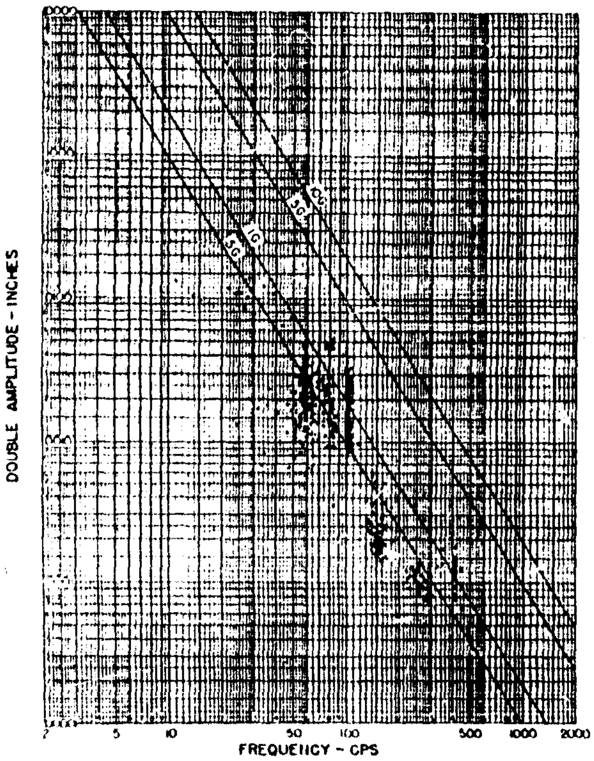

Figure 51. DIRECTION VERT
LOCATION SUNSTRAND CONSTANT SPEED DRIVE FOR 30KVA ALTERNATOR F.S. 568

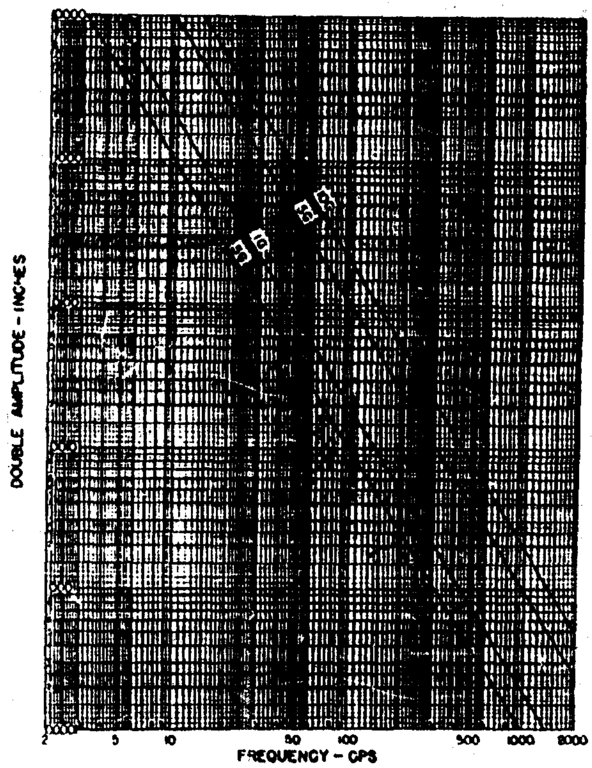

Figure 52. DIRECTION LAT
LOCATION SUNSTRAND CONSTANT SPEED DRIVE FOR 30KVA ALTERNATOR F.S. 568

Figures 49 to 52. Summary Plots for Individual Vibration Pickups

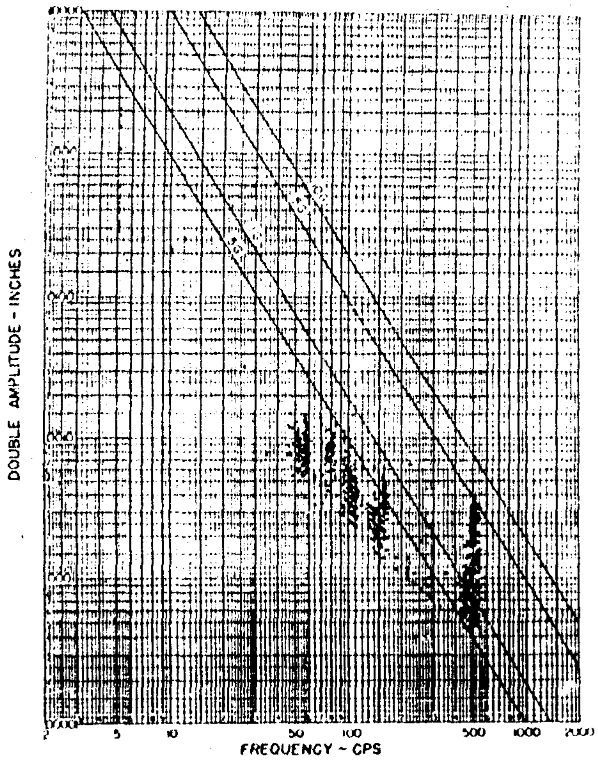

Figure 53. DIRECTION LAT
LOCATION FWD END OF ACCESSORY SECTION OF J 57-P13 ENGINE F.S. 568

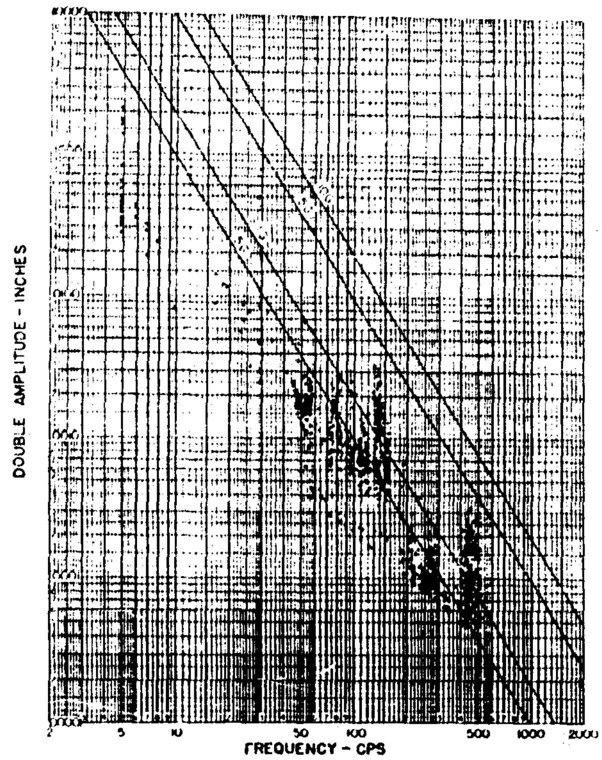

Figure 54. DIRECTION VERT
LOCATION FWD END OF ACCESSORY SECTION OF J 57-P13 ENGINE F.S. 568

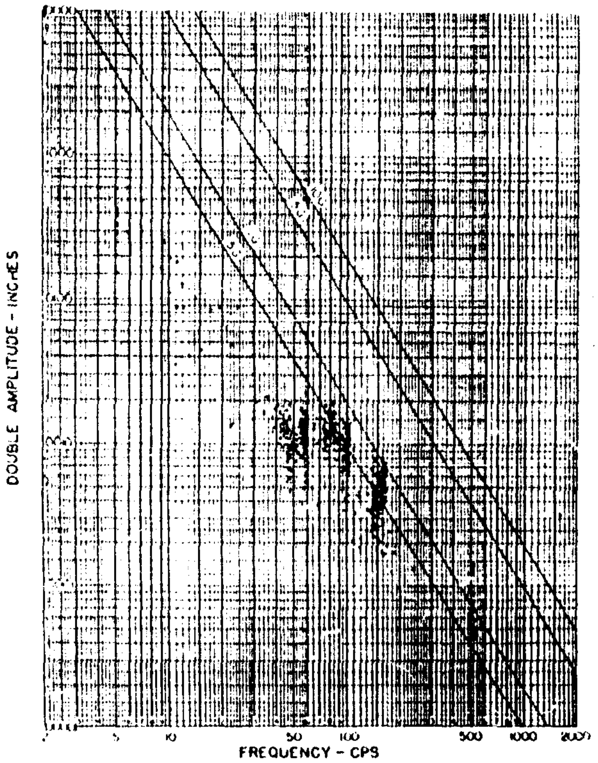

Figure 55. DIRECTION LAT
LOCATION FWD END OF COMPRESSOR SECTION OF J-57-P13 ENGINE

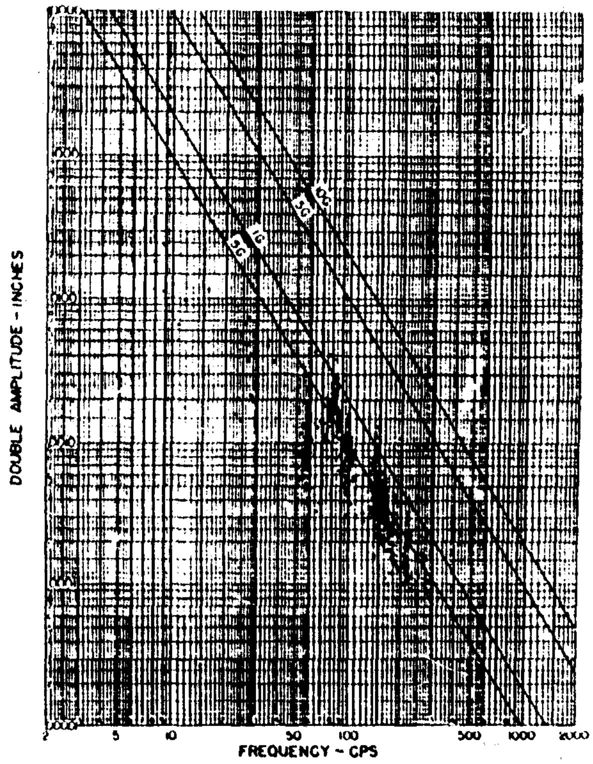

Figure 56. DIRECTION VERT
LOCATION FWD END OF COMPRESSOR SECTION OF J-57-P13 ENGINE

Figures 53 to 56. Summary Plots for Individual Vibration Pickups

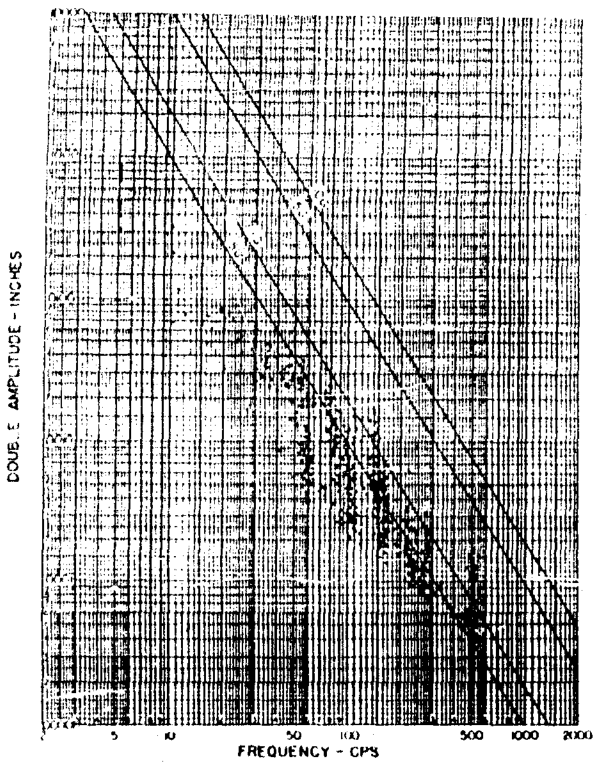

Figure 57. DIRECTION VERT
LOCATION NOZZLE SECTION OF J-57-P ENGINE F.S 568

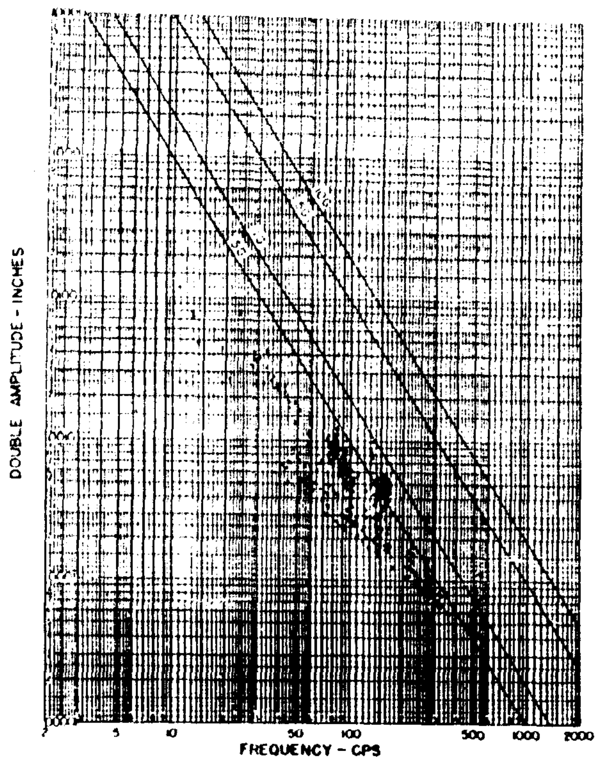

Figure 58. DIRECTION LAT
LOCATION NOZZLE SECTION OF J-57-P15 ENGINE F.S 568

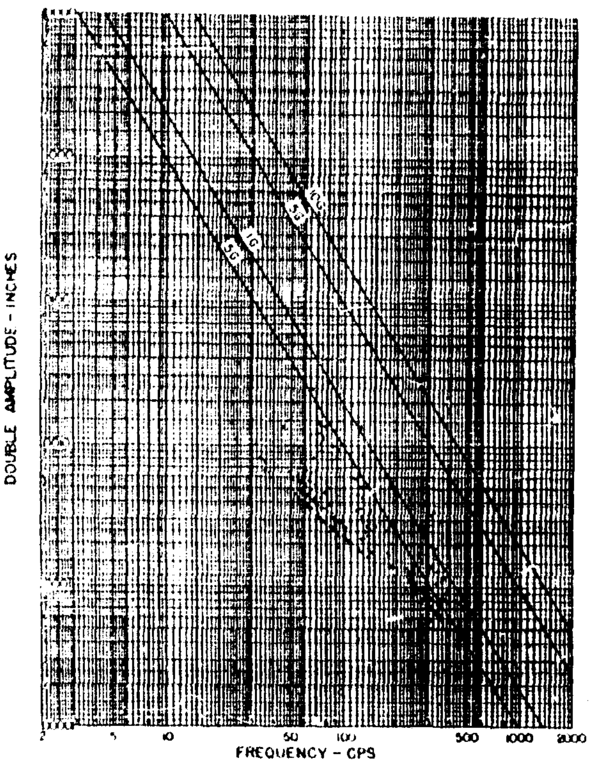

Figure 59. DIRECTION F/A
LOCATION STRUCTURE OF FWD ELECTRONIC COMPARTMENT
F.S 235

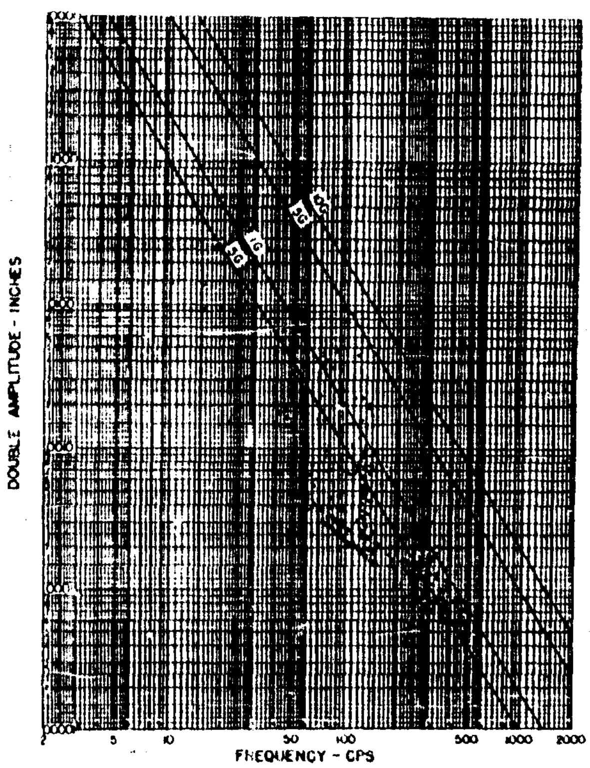

Figure 60. DIRECTION LAT
LOCATION STRUCTURE OF FWD ELECTRONIC COMPARTMENT
F.S 235

Figures 57 to 60. Summary Plots for Individual Vibration Pickups

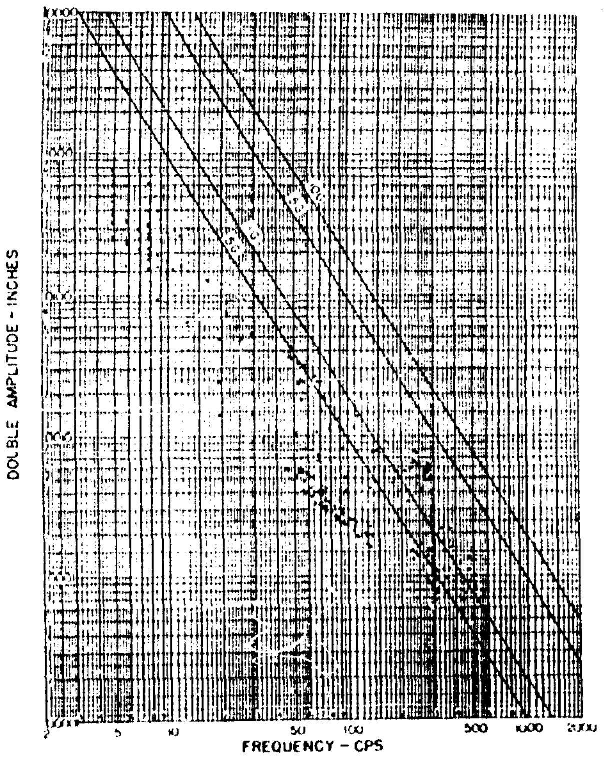

Figure 61. DIRECTION VERT
LOCATION STRUCTURE OF FWD ELECTRONIC COMPARTMENT F S 235

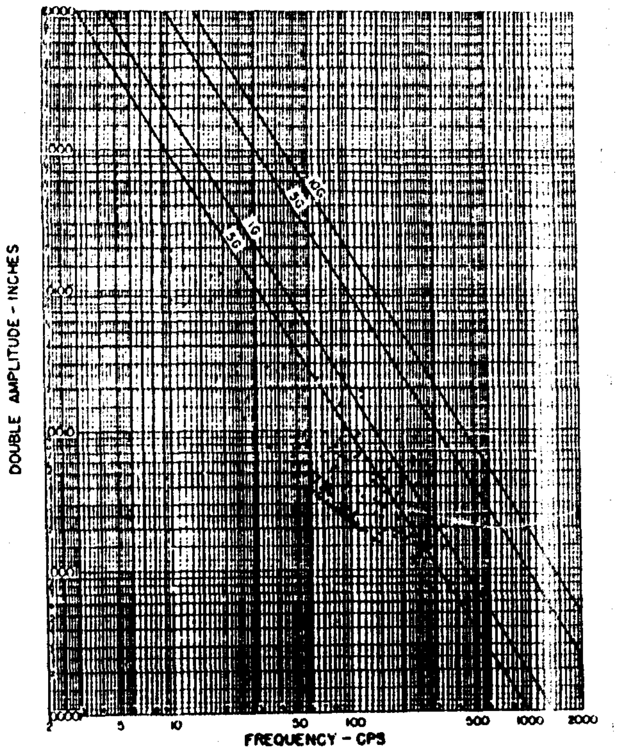

Figure 62. DIRECTION LAT
LOCATION STRUCTURE OF RADIO COMPARTMENT F S 290

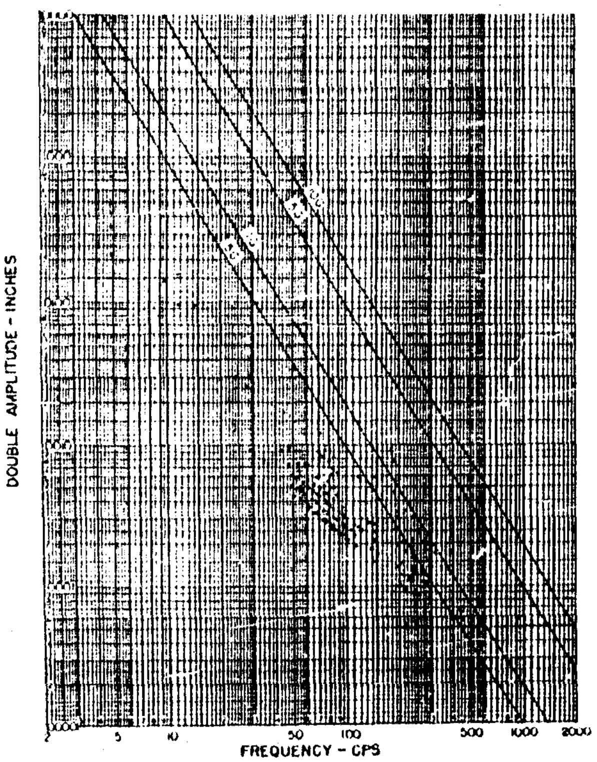

Figure 63. DIRECTION F/A
LOCATION STRUCTURE OF RADIO COMPARTMENT F S 290

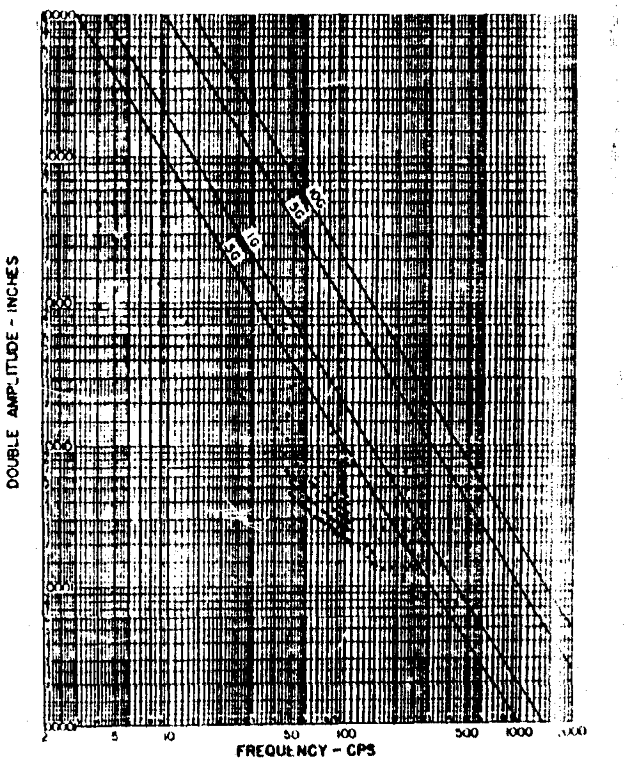

Figure 64. DIRECTION VERT
LOCATION STRUCTURE OF RADIO COMPARTMENT F S 290

Figures 61 to 64. Summary Plots for Individual Vibration Pickups

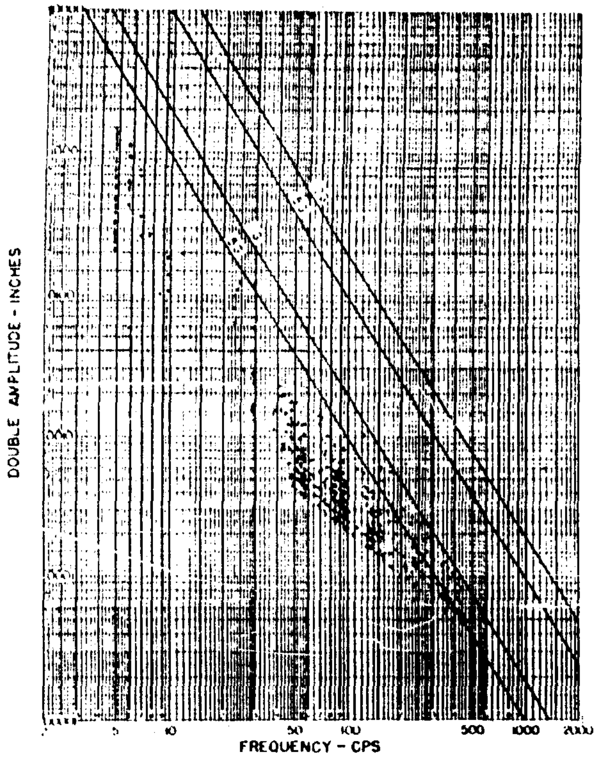

Figure 65. DIRECTION VERT
LOCATION STRUCTURE OF RT WHEEL WELL F.S. 546

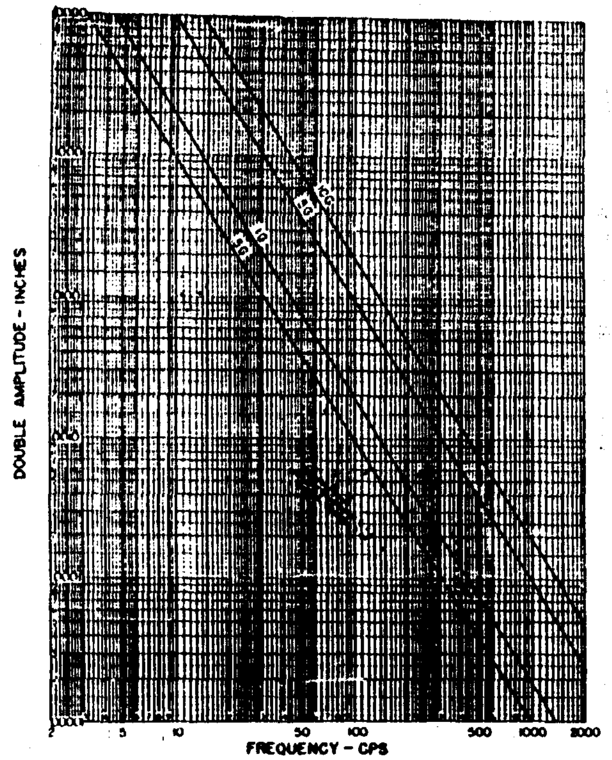

Figure 66. DIRECTION LAT
LOCATION STRUCTURE OF RT WHEEL WELL F.S. 546

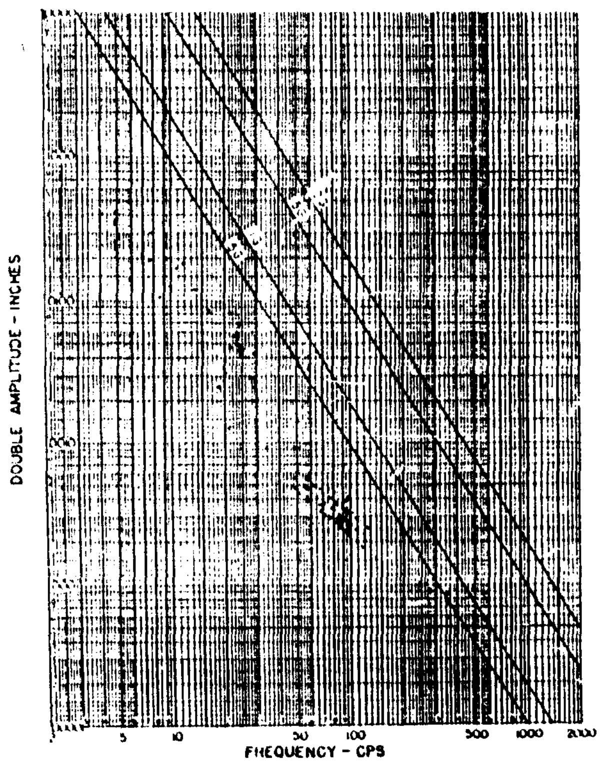

Figure 67. DIRECTION F/A
LOCATION STRUCTURE OF RT WHEEL WELL F.S. 546

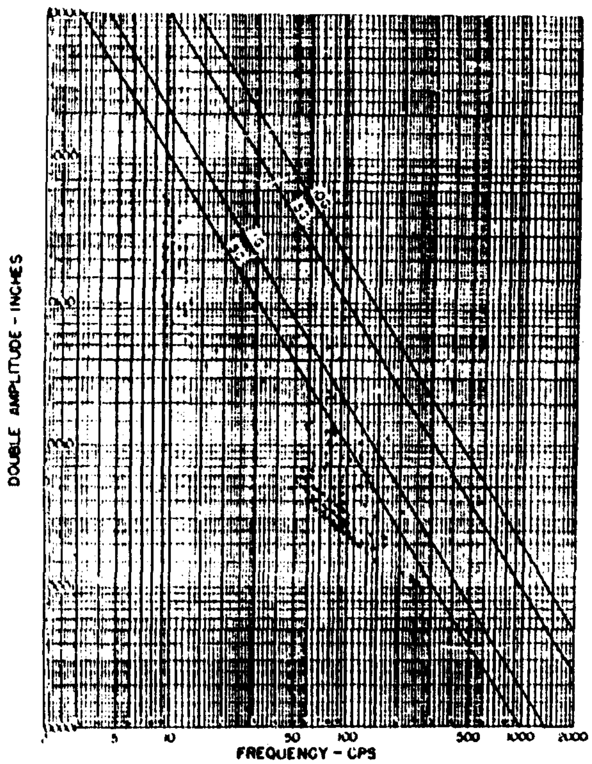

Figure 68. DIRECTION VERT
LOCATION STRUCTURE ABOVE BATTERY F.S. 196

Figures 65 to 68. Summary Plots for Individual Vibration Pickups

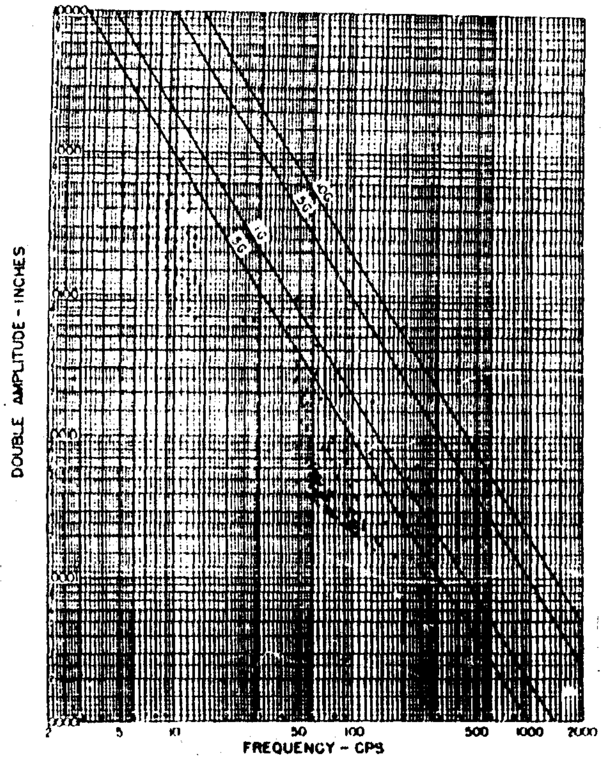

Figure 69. DIRECTION LAT
LOCATION STRUCTURE ABOVE BATTERY F.S.196

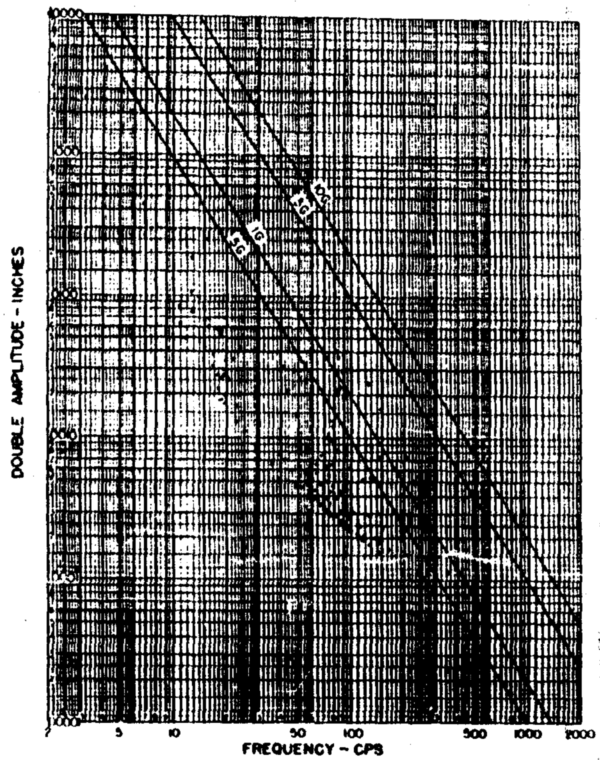

Figure 70. DIRECTION F/A
LOCATION STRUCTURE ABOVE BATTERY F.S.196

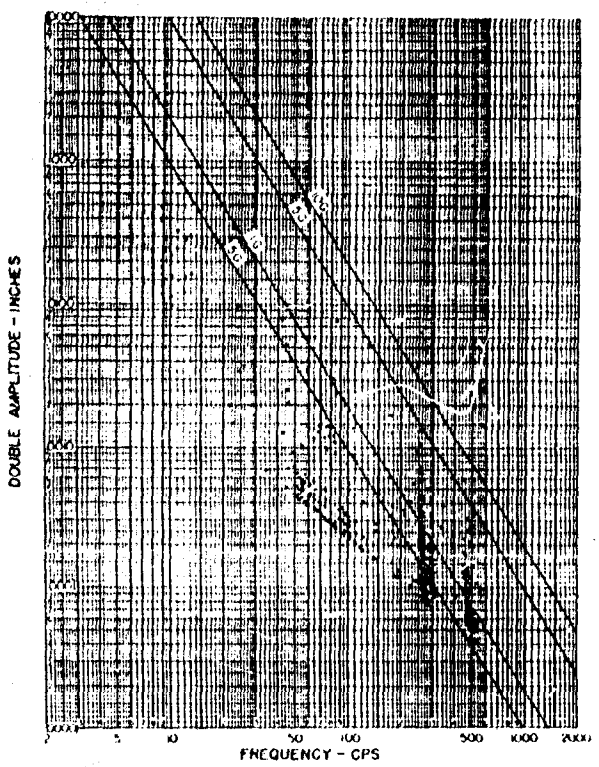

Figure 71. DIRECTION LAT
LOCATION LEFT SIDE OF NOSE STRUCTURE F.S.196

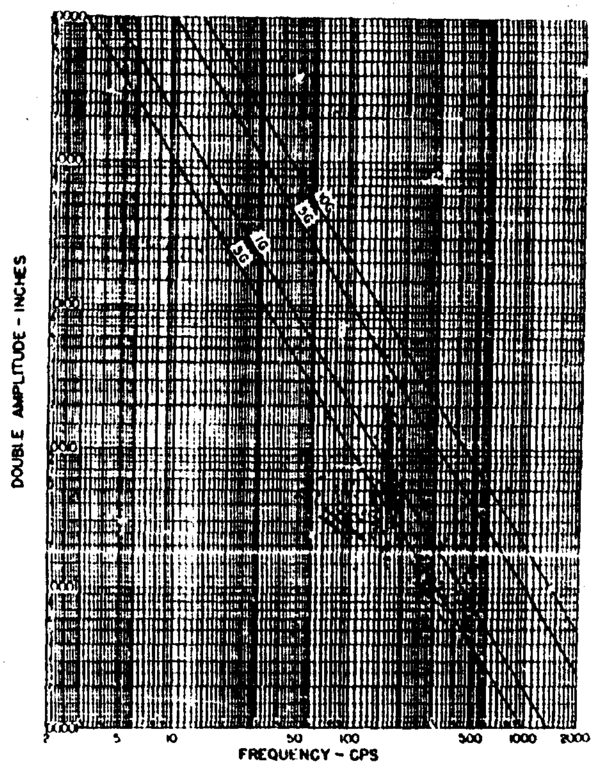

Figure 72. DIRECTION LAT
LOCATION RIGHT SIDE OF A/C FUSELAGE F.S.342

Figures 69 to 72. Summary Plots for Individual Vibration Pickups

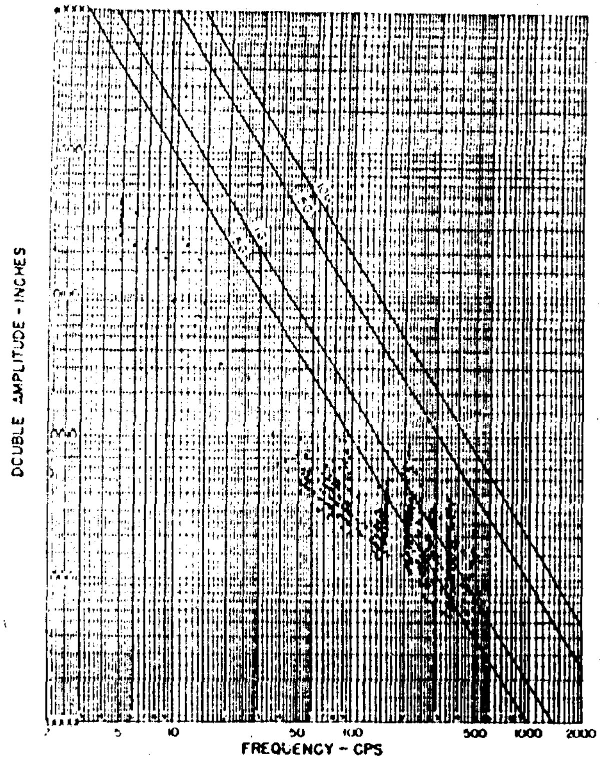

Figure 73. DIRECTION LAT
LOCATION RIGHT SIDE OF A/C FUSELAGE F S 524

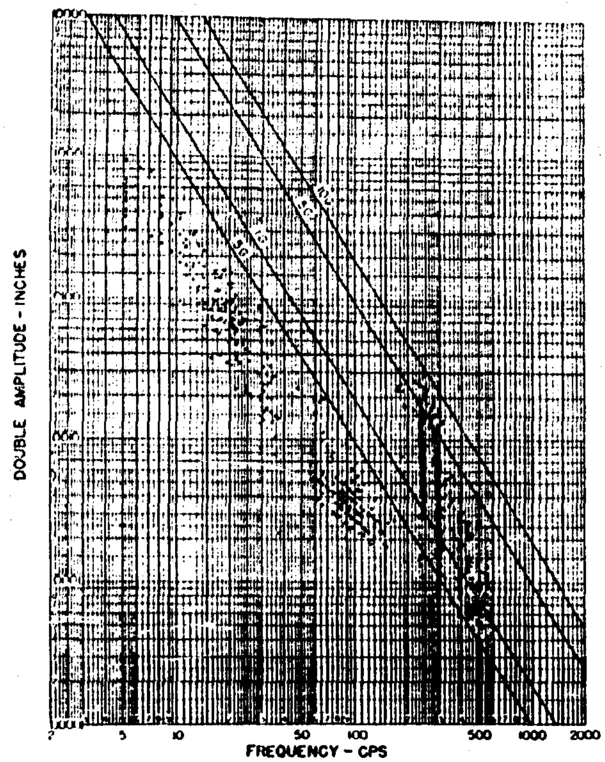

Figure 74. DIRECTION LAT
LOCATION RIGHT SIDE OF A/C FUSELAGE AFT SECTION
F S 680

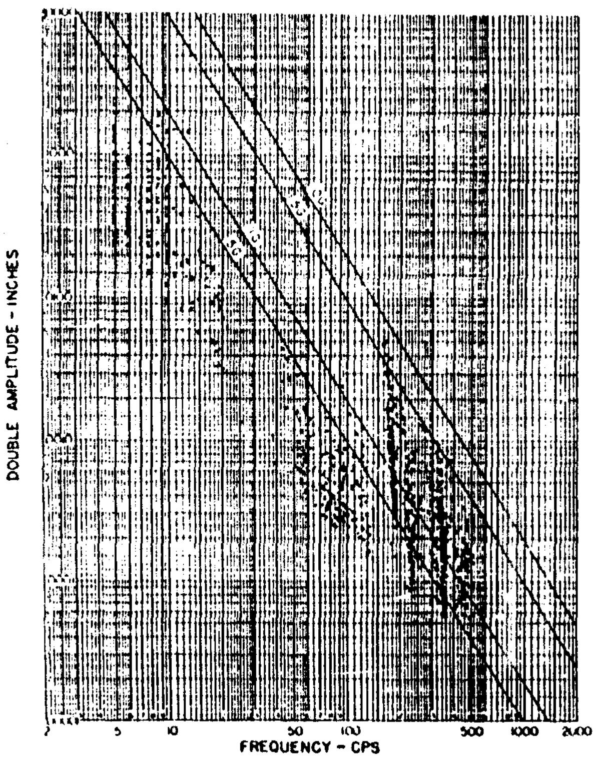

Figure 75. DIRECTION LAT
LOCATION RIGHT SIDE OF A/C FUSELAGE AFT SECTION
F S 814

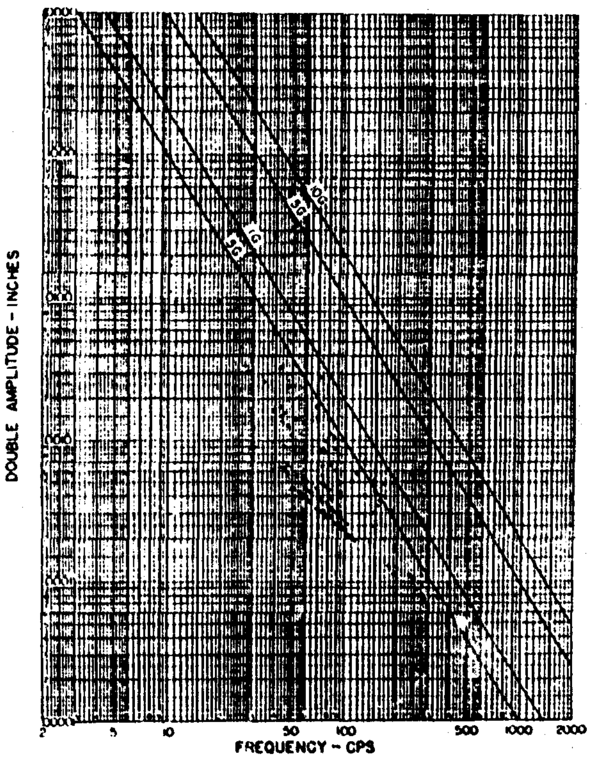

Figure 76. DIRECTION VERT
LOCATION ELECTRONIC EQUIPMENT COMPARTMENT F S 296

Figures 73 to 76. Summary Plots for Individual Vibration Pickups

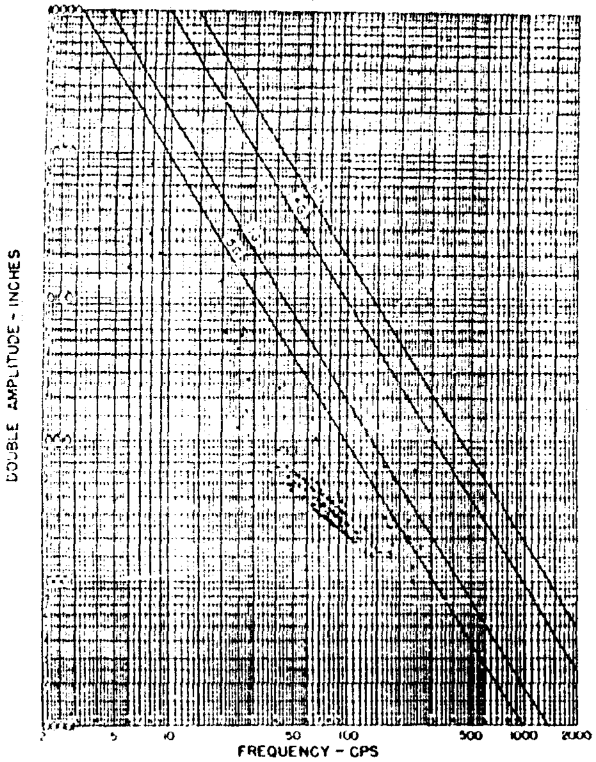

Figure 77. DIRECTION LAT
LOCATION ELECTRONIC EQUIPMENT COMPARTMENT F.S 296

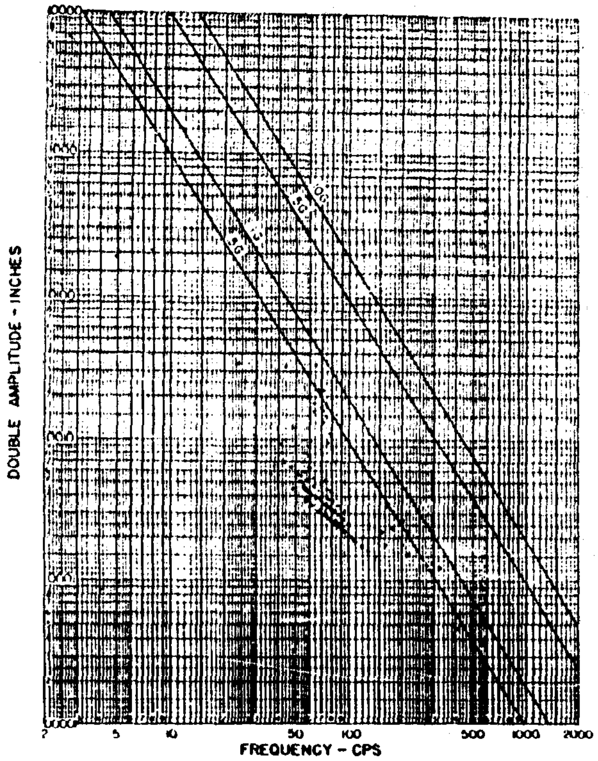

Figure 78. DIRECTION F/A
LOCATION ELECTRONIC EQUIPMENT COMPARTMENT F.S 296

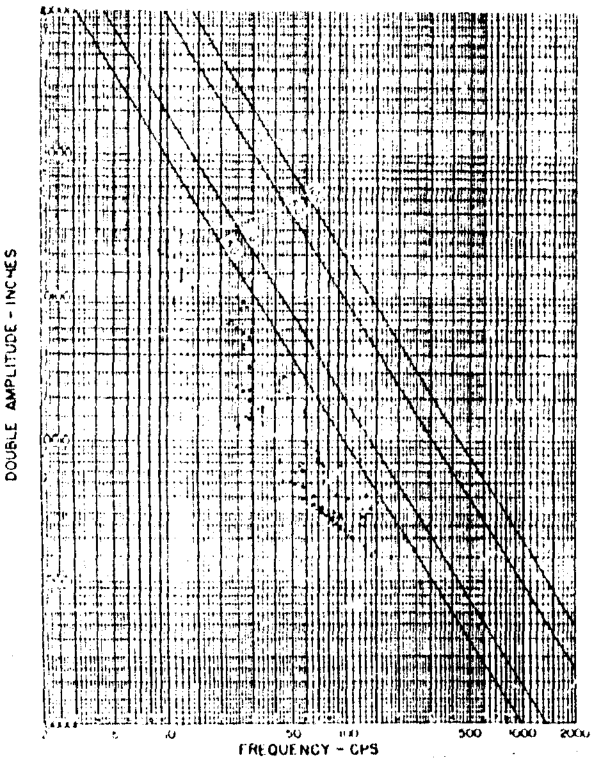

Figure 79. DIRECTION F/A
LOCATION INSTRUMENT PANEL F.S 230

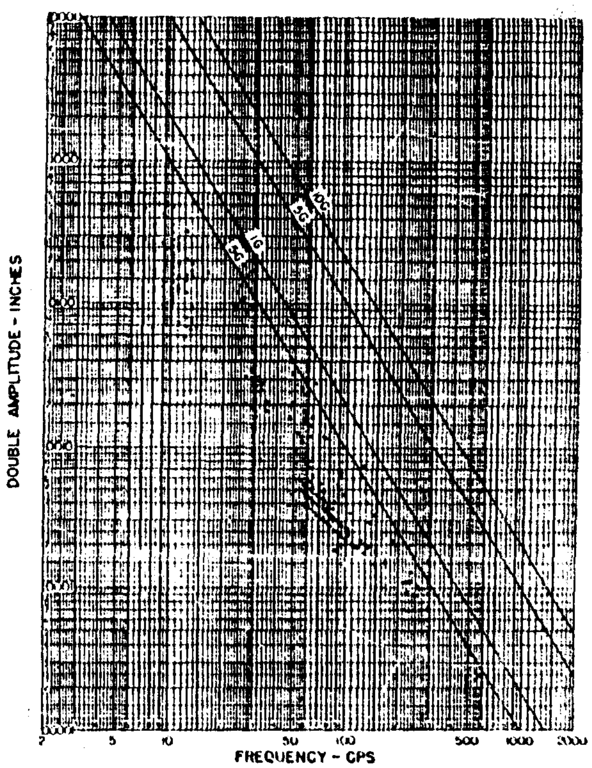

Figure 80. DIRECTION LAT
LOCATION INSTRUMENT PANEL F.S 230

Figures 77 to 80. Summary Plots for Individual Vibration Pickups

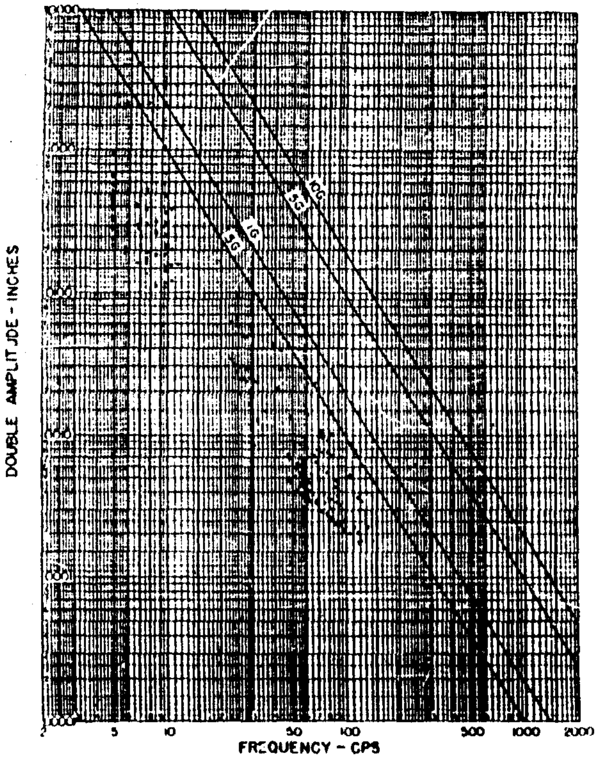

Figure 81. DIRECTION VERT
LOCATION INSTRUMENT PANEL F S 230

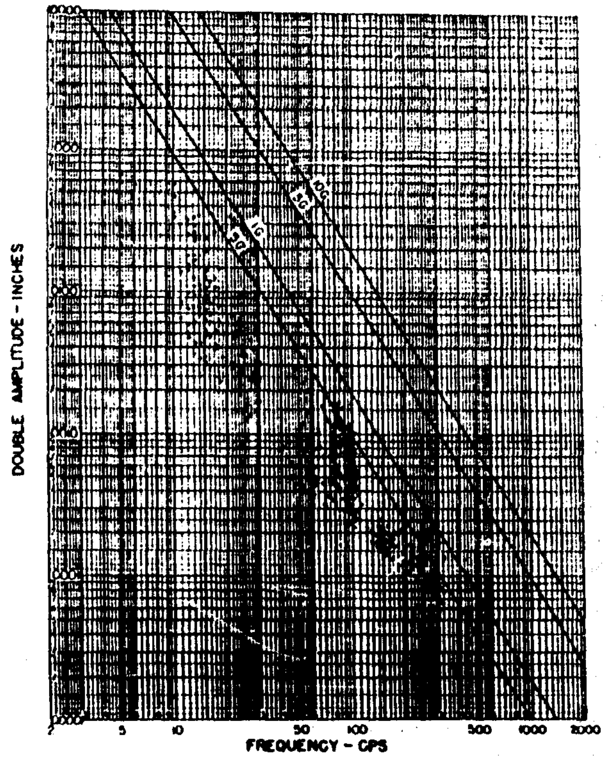

Figure 82. DIRECTION F/A
LOCATION RT WINGTIP F S 600

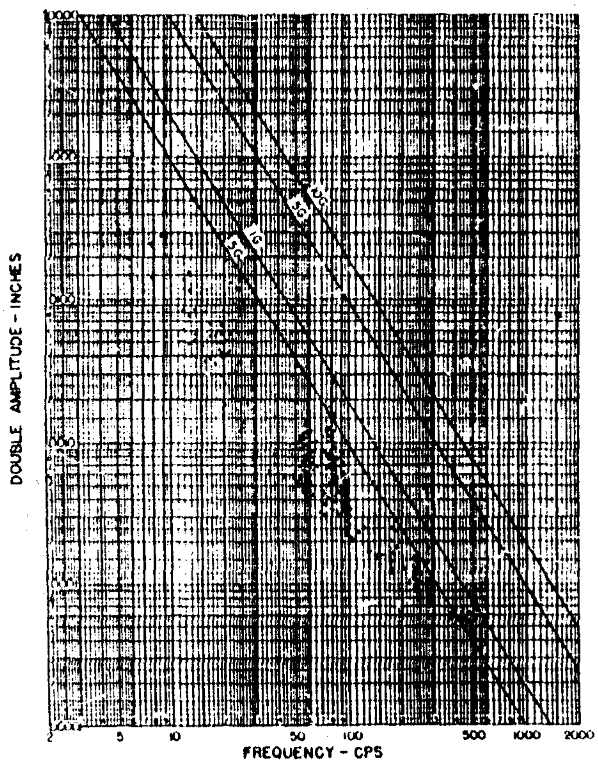

Figure 83. DIRECTION LAT
LOCATION RT WINGTIP F S 600

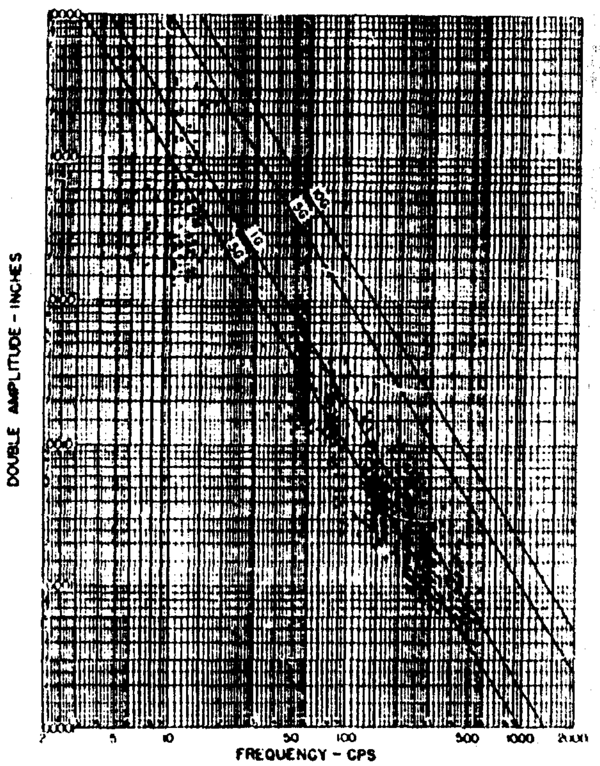

Figure 84. DIRECTION VERT
LOCATION RT WINGTIP F S 600

Figures 81 to 84. Summary Plots for Individual Vibration Pickups

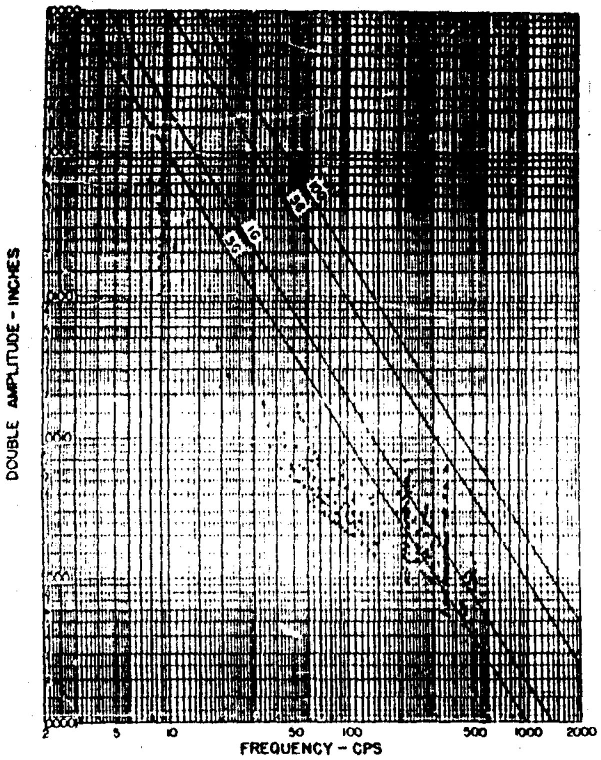

Figure 85. DIRECTION VERT
LOCATION STRUCTURE OF VERTICAL FIN F.S 783

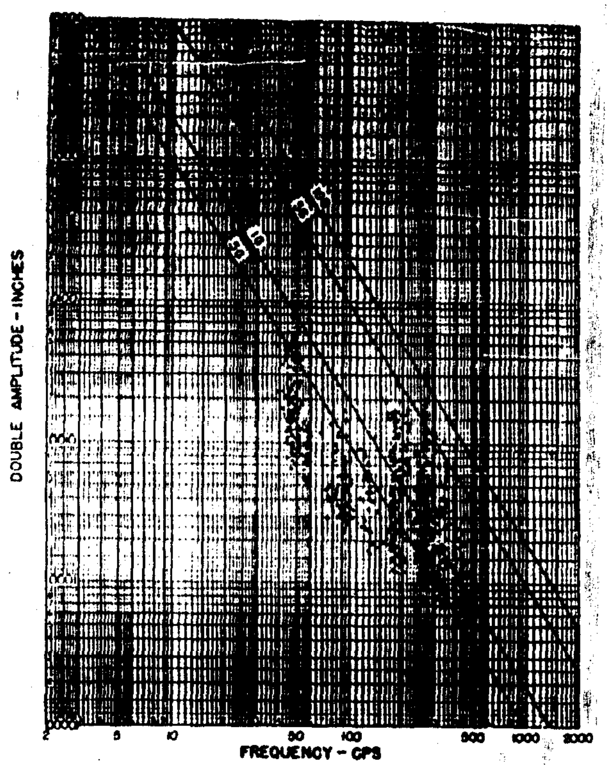

Figure 86. DIRECTION LAT
LOCATION STRUCTURE OF VERTICAL FIN F.S 783

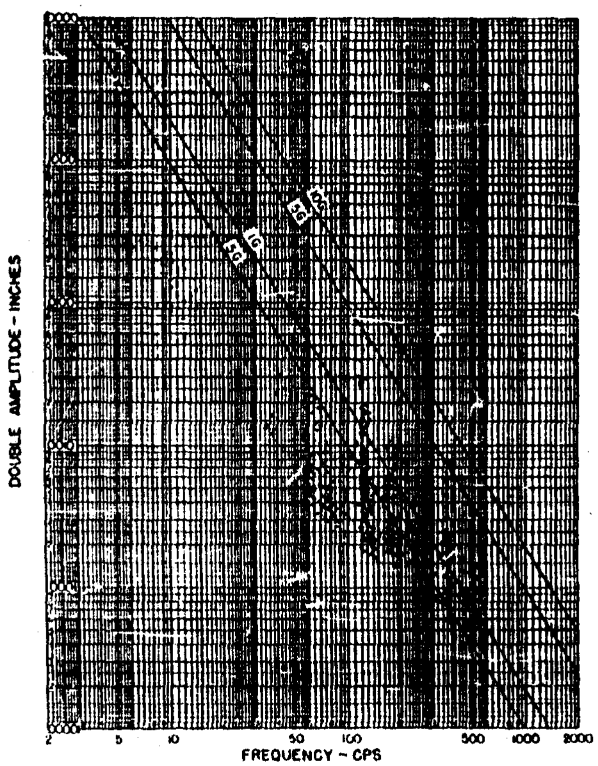

Figure 87. DIRECTION F/A
LOCATION STRUCTURE OF VERTICAL FIN F.S 783

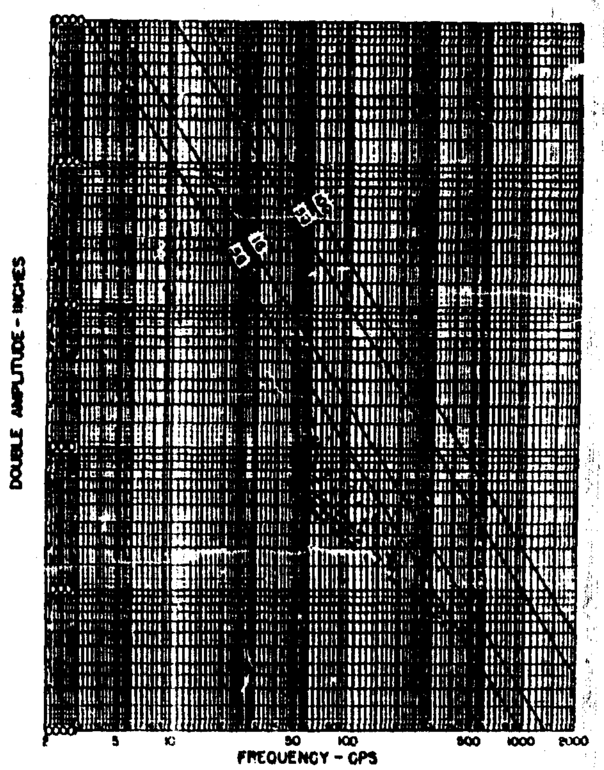

Figure 88. DIRECTION VERT
LOCATION STABILATOR ACTUATOR PLATE F.S. 814

Figures 85 to 88. Summary Plots for Individual Vibration Pickups

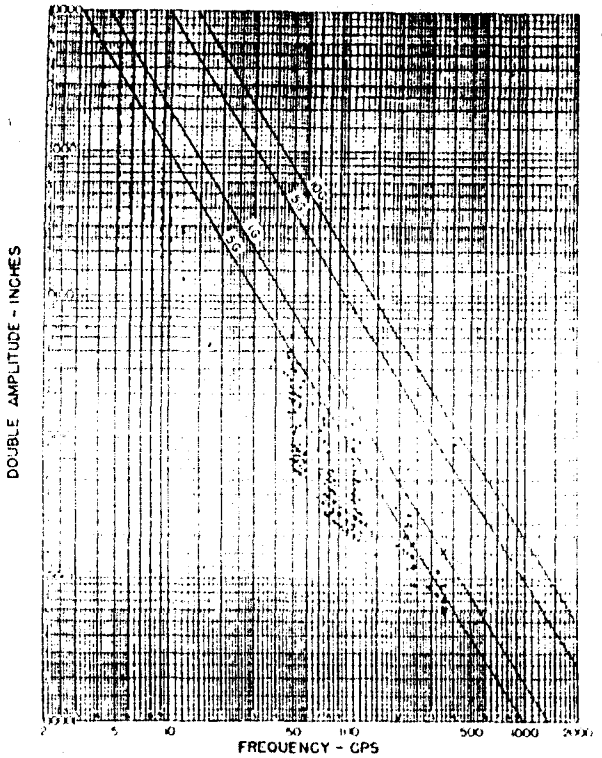

Figure 89. DIRECTION LAT
LOCATION STABILATOR ACTUATOR PLATE F S 814

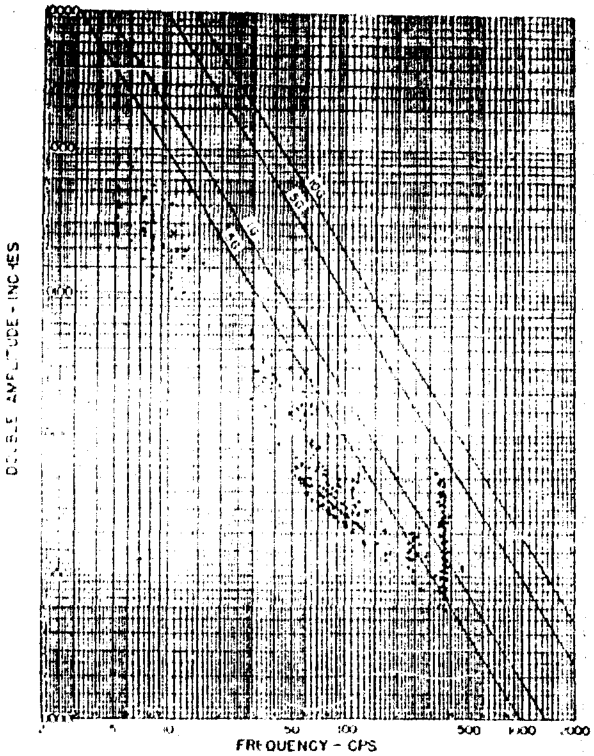

Figure 90. DIRECTION F/A
LOCATION STABILATOR ACTUATOR PLATE F S 814

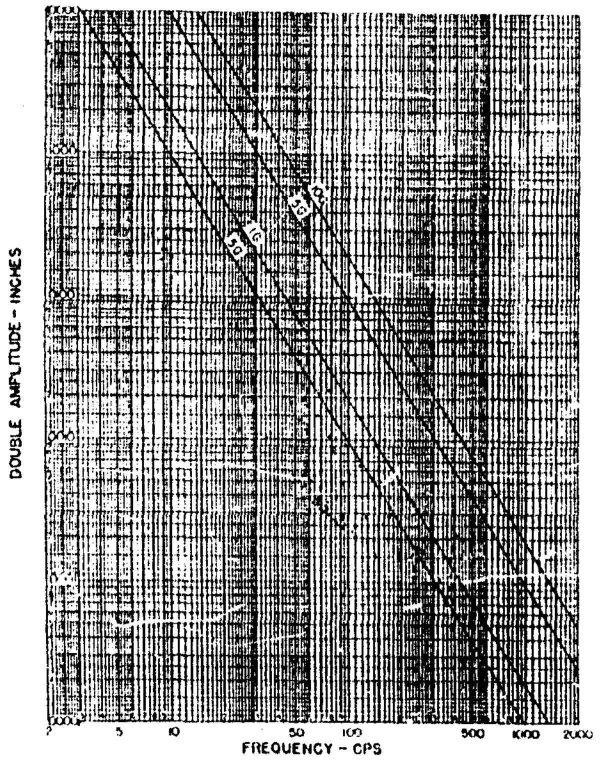

Figure 91. DIRECTION VERT
LOCATION PILOT'S SEAT RAIL F S 206

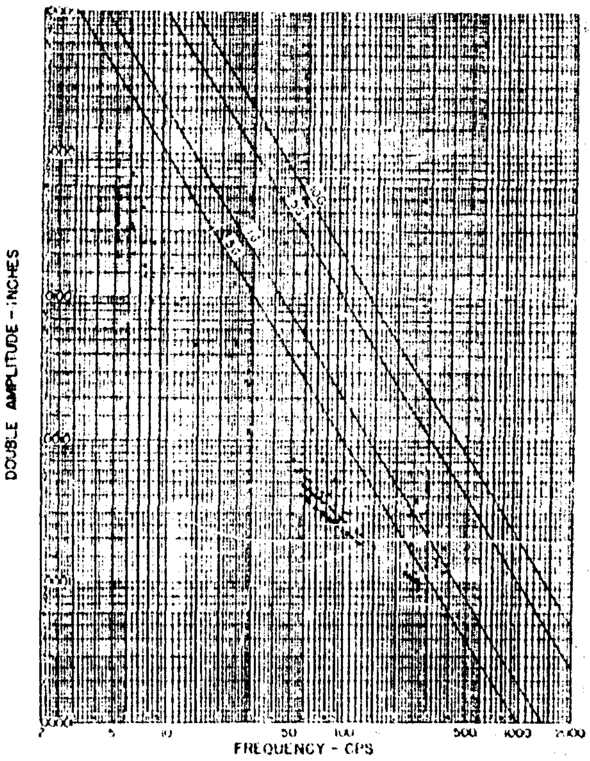

Figure 92. DIRECTION LAT
LOCATION PILOT'S SEAT RAIL F S 206

Figures 89 to 92. Summary Plots for Individual Vibration Pickups

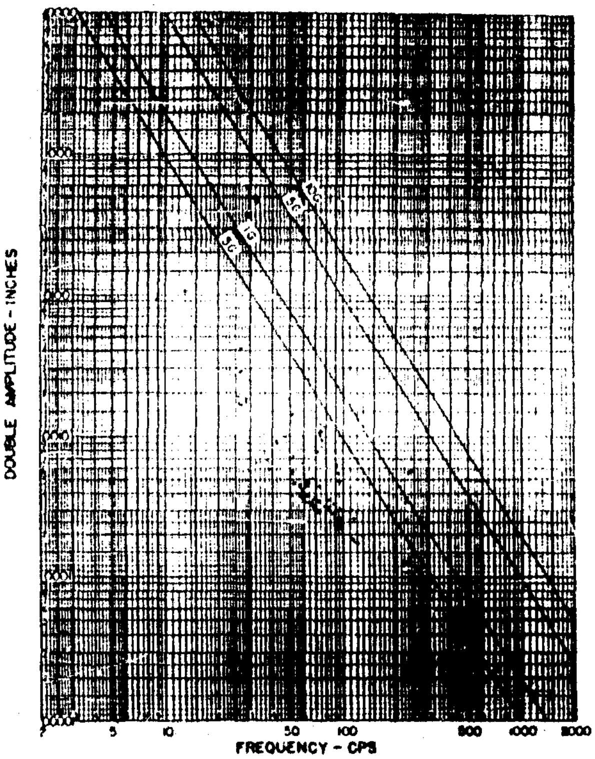

Figure 93. DIRECTION F/A
LOCATION PILOT'S SEAT RAIL F S [illegible]

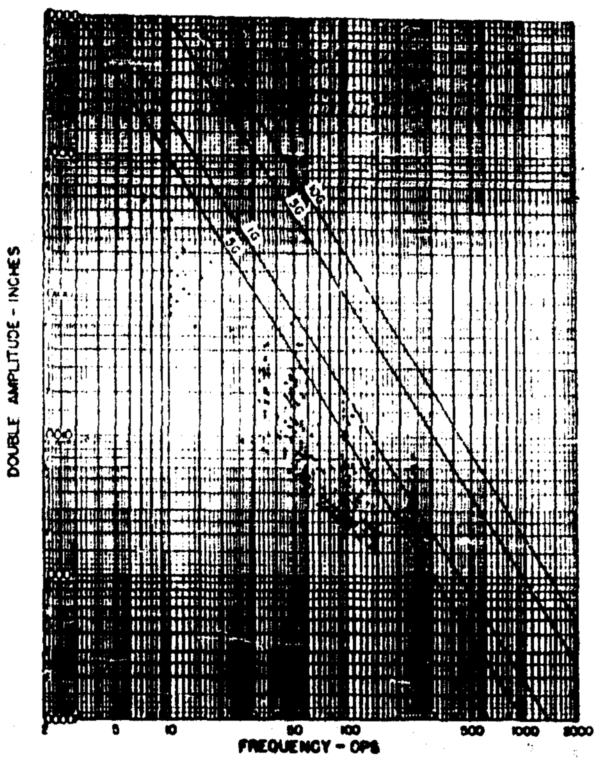

Figure 94. DIRECTION VERT
LOCATION AFT SECTION STRUCTURE RT SIDE F S 692

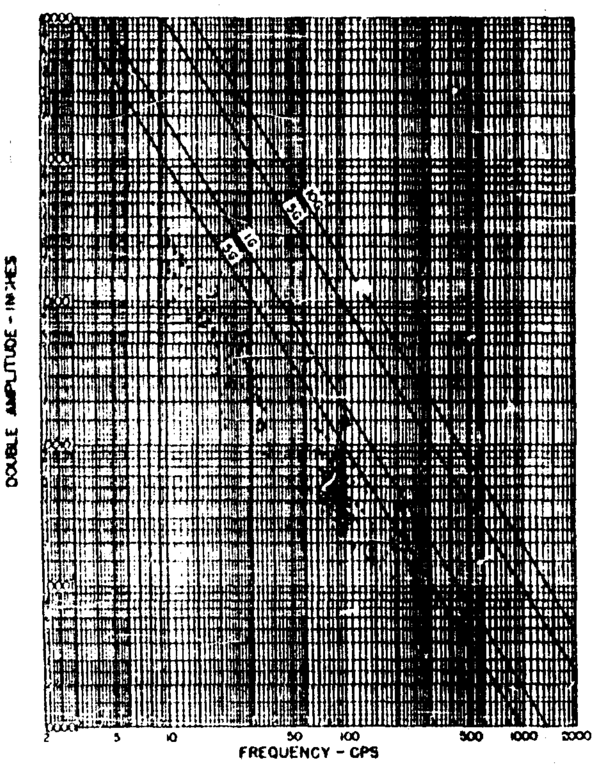

Figure 95. DIRECTION LAT
LOCATION AFT SECTION STRUCTURE RT SIDE F S 692

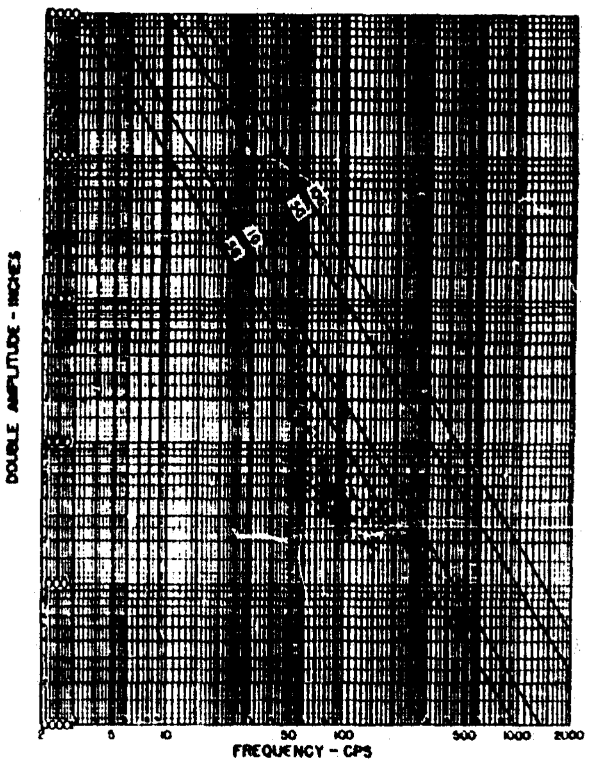

Figure 96. DIRECTION F/A
LOCATION AFT SECTION STRUCTURE RT SIDE F S 692

Figures 93 to 96. Summary Plots for Individual Vibration Pickups

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AERONAUTICAL SYSTEMS DIVISION, FLIGHT ENGINEERING TEST GROUP, Wright-Patterson AFB, Ohio, FLIGHT VIBRATION SURVEY OF F-101A AIRCRAFT, by Charles E. Thomas, May 1961. 39p. incl. figs. and tables. (Project 1309; Task 13004) (ASD TN 61-60)
Unclassified report

The F-101A aircraft was surveyed to determine the vibration environment existing thorughout the vehicle under all flight conditions expected in service. Approximately 32,630 data points were obtained from 25 separate locations on the vehicle during 31 test flights. The data obtained in this

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survey were evaluated to determine the vibration test requirements which should be specified for items of equipment to be used on the F-101A aircraft. The data indicated that, in general, the vibration testing requirements listed in Specification MIL-E-5272 are more than adequate for F-101A equipment.

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